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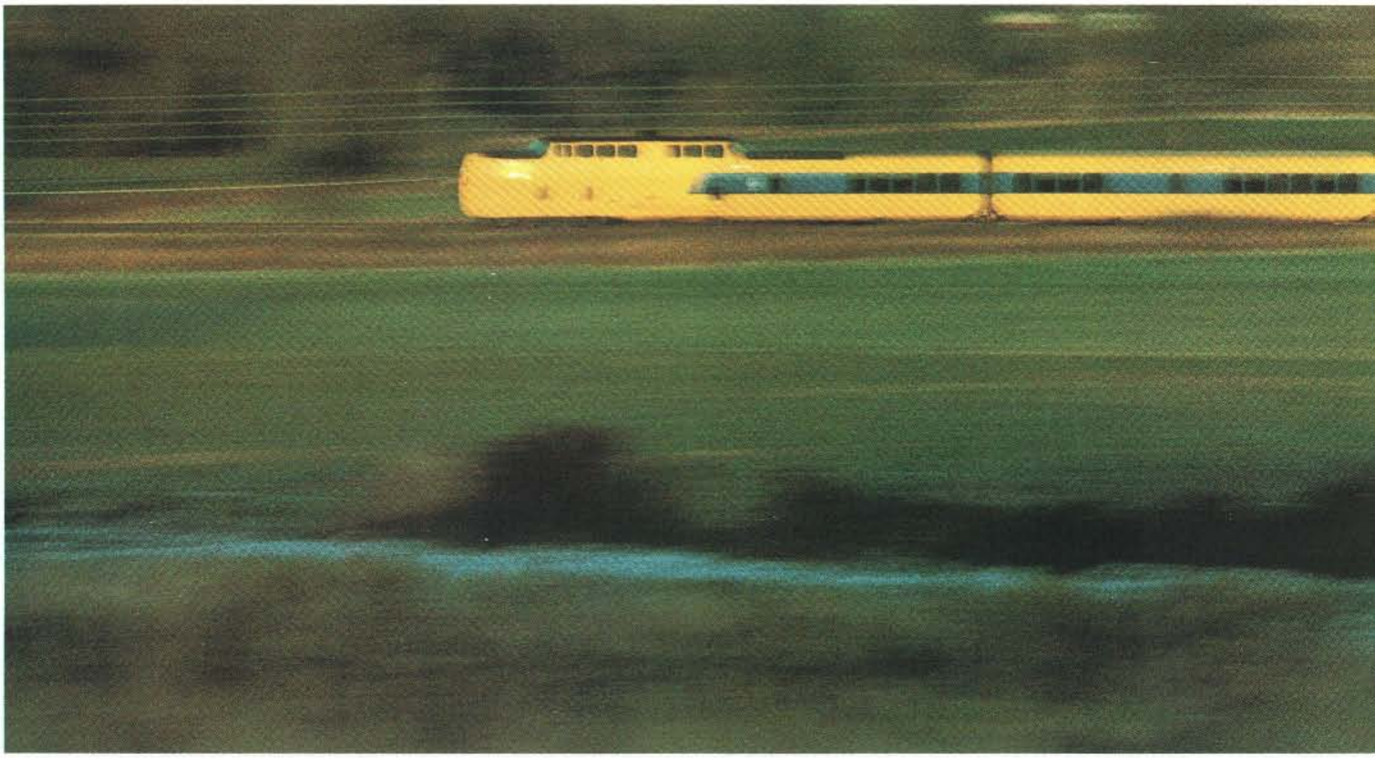

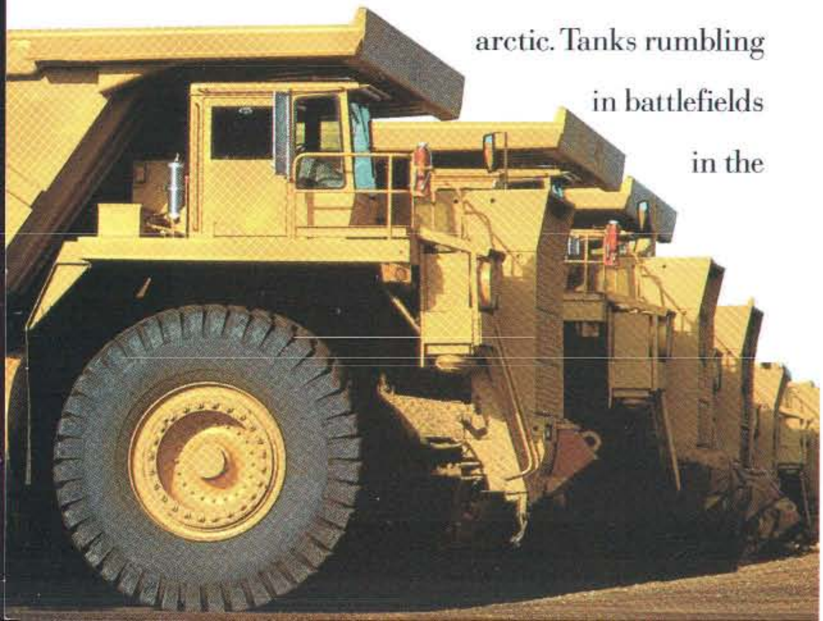

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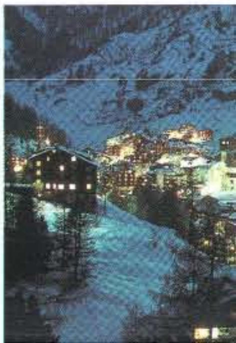

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February 1992 Volume 266 Number 2

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Indochinese Refugee Families and Academic Achievement

Nathan Caplan, Marcella H. Choy and John K. Whitmore

Many refugees from Southeast Asia arrived in the U.S. with little more than the clothes on their backs and with no exposure to Western culture or knowledge of the English language. Yet their children display stunning scholastic achievement in American schools. The authors attribute this academic success to supportive families in which all members participate equally in the learning process.

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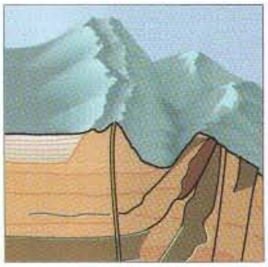

Mud Volcanoes of the Marianas

Patricia Fryer

Near the edge of the Mariana Trench, where the great Pacific plate of the earth's crust is being forced down into the mantle, mountains of green mud loom from the ocean floor. These unusual mud volcanoes have solved a geologic mystery. Their presence confirms a theory that water squeezed from descending plates reacts with the mantle, creating minerals that ooze back to the seafloor.

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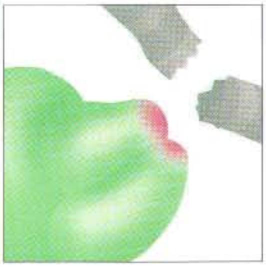

Cancer Cell Invasion and Metastasis

Lance A. Liotta

The deadly ability of cancer cells to spread throughout the body and invade healthy tissues is not purely a malign aberration. The complex process is a natural characteristic of many normal cells. Recent identification of regulatory genes and proteins that control metastasis has produced a promising class of synthetic drugs that may prevent or block the growth of secondary tumors.

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The Mammals of Island Europe

Gerhard Storch

Fifty million years ago the island that is now Europe was colonized by animals from Africa and the New World. Their extraordinarily detailed fossil images are engraved in the shale of an ancient lake bed near Messel in Germany.

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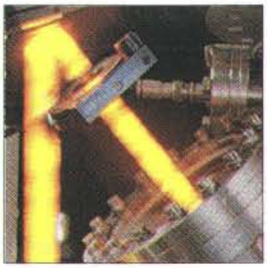

Laser Trapping of Neutral Particles

Steven Chu

Atoms normally zip along with Brownian abandon at speeds of several hundred miles an hour. Getting atoms to remain still for detailed study was impossible until researchers cooled them in an "optical molasses" of laser light. Since then, workers have created optical traps and tweezers, molecular fountains—even an atomic trampoline. All are important tools for physics, chemistry and biology.

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Turquoise in Pre-Columbian America

Garman Harbottle and Phil C. Weigand

Centuries before the arrival of the conquistadores, dazzling ornaments encrusted with turquoise already had great religious, social and economic significance in Mesoamerica. Yet the nearest deposits of this gemstone are 1,000 miles away. Trade routes extended to Nevada and Arizona, in the American Southwest.

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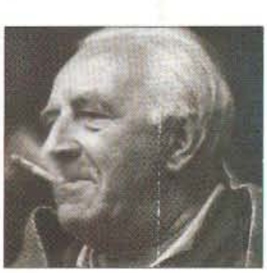

Nikolai V. Timoféeff-Ressovsky

Diane B. Paul and Costas B. Krimbas

Can a scientist be productive in a society that challenges human values? The life of Russian geneticist Timoféeff-Ressovsky offers some answers. He worked in Nazi Germany, was imprisoned by the Soviets and continued his research in a military laboratory. After receiving amnesty in 1955, he opposed the Lysenkoists.

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TRENDS IN CONSUMER ELECTRONICS

Picture Perfect

Elizabeth Corcoran, staff writer

As Europeans watched foreign competition ravage the U.S. electronics industry, they vowed that it would not happen there. They drew the line with high-definition television and set out to develop a uniquely European system. After a six-year government-industry effort, broadcasts are beginning. Will the rush into HDTV assure the technological competitiveness of a unified Europe?

DEPARTMENTS

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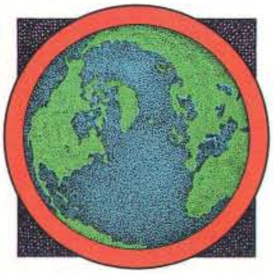

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Essay: *Geoffrey Burbidge*

The momentum of the big bang bandwagon.

THE COVER portrays six laser beams that are used to cool atoms to temperatures near absolute zero. The beams are part of an elaborate apparatus that measures the energy states of atoms with extreme precision. Such research has demonstrated the feasibility of an improved atomic clock, and it has led to better measurements of the force of gravity. Laser techniques have also been applied to manipulate individual molecules, cells and other microscopic objects (see "Laser Trapping of Neutral Particles," by Steven Chu, page 48).

THE ILLUSTRATIONS

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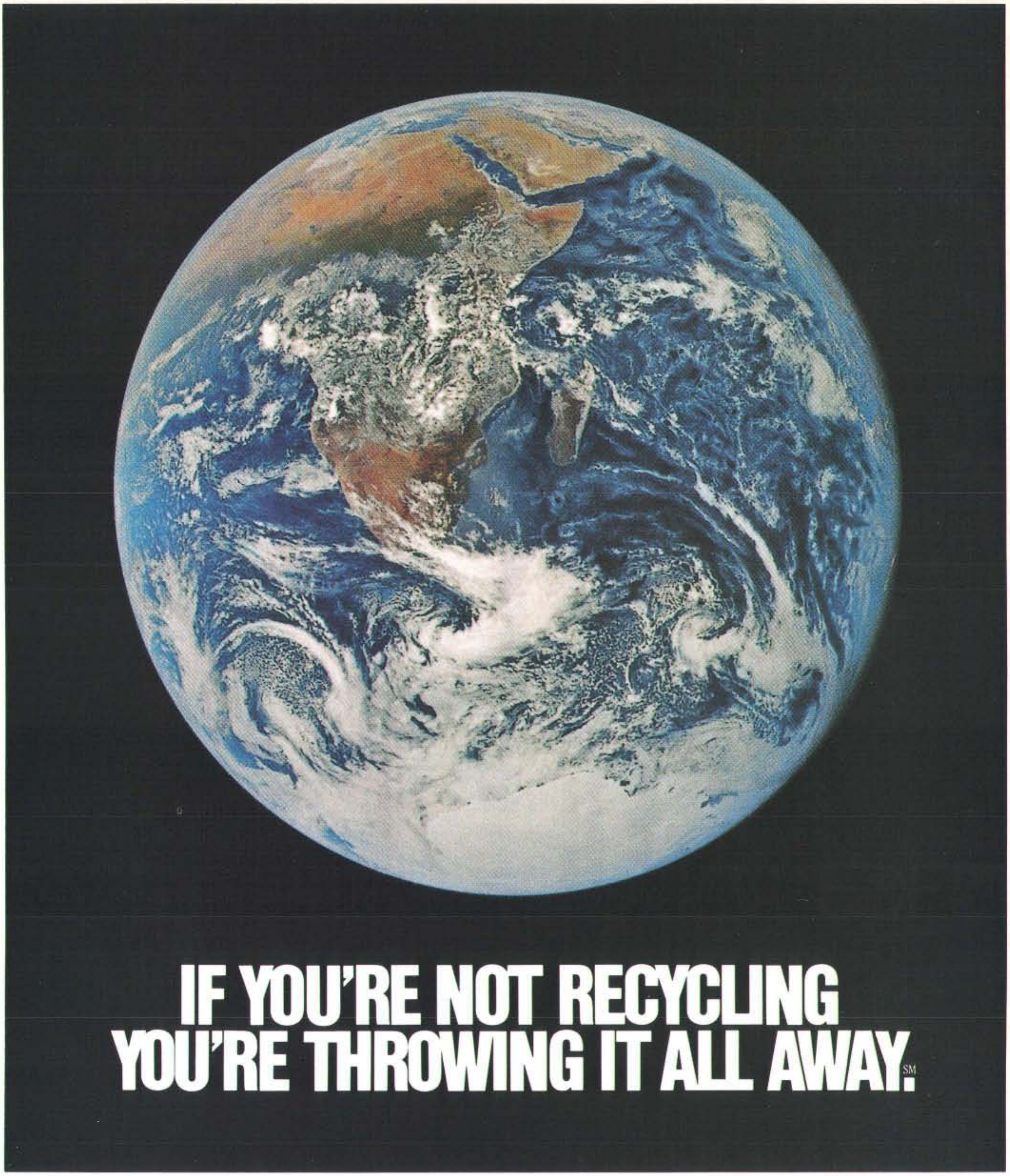

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LETTERS TO THE EDITORS

Tomorrow's World Today

The September 1991 special issue of Scientific American, "Communications, Computers and Networks," is wonderful. There hasn't been anything in print that comes close to the quality of material that you assembled to cover these critical technologies and how they have the potential to change our lives. I'm reluctant to suggest that it's incomplete, but I can't help making some related observations.

During the past few decades, rapid improvements in mass communications and transportation have taken place, but personal communications has not kept pace. Moreover, the changes in mass communications and transportation have disrupted or destroyed many vital community structures. Entertainment and information have become entities that separate people emotionally, while transportation has separated them physically. Improvements in personal communications, such as answering machines and call waiting, have not helped re-create communities.

Powerful communications systems based on networking and computer technologies can address social issues. They can help with the problem of latchkey children, for example, by allowing parents to work from home in the afternoon when their children return from school. The network can also be a mediator of communication among teachers, parents and students.

Nick Arnett
Multimedia Computing Corporation
Santa Clara, Calif.

In "Infrastructure for the Global Village" [Scientific American, September 1991], Senator Al Gore calls for a national "data superhighway," by analogy with the national transportation infrastructure. But private concerns built the first successful turnpikes in both England and America, and the examples of the Great Northern railroad and commercial airlines demonstrate that the free market can succeed in any transportation sphere. Government involvement, on the other hand, brings characteristic problems: public subsidy of highways has helped the trucking industry at the expense of rail transportation and has contributed to urban sprawl and pollution by shifting real costs away from drivers. Now Senator Gore wants to do the same thing to high-speed data communications, despite abundant evidence that the private sector is solving the problem on its own.

Steven B. Harris
Los Angeles

Senator Gore's technopopulist vision of a supercomputing Route 66 would be appealing except that I operate a motor vehicle in Massachusetts. I imagine this digital interstate backed up for miles, its attendant bureaucracy perpetuating itself ad infinitum through obscure bond issues and a network of fiber-optic tollbooths, its body of regulations so vast, oblique and shrouded in cryptic jargon that only the lawyers who wrote it would understand it.

John Gately Luz
Newton, Mass.

Austronesian Origins

Peter Bellwood's description of the expansion of Austronesian from the mainland of Southeast Asia into the remote Pacific is very plausible indeed, but only if one leaves out the people ["The Austronesian Dispersal and the Origin of Languages," Scientific American, July 1991]. Analyses of the skeletons of living and prehistoric inhabitants of the area show that the modern Polynesians and Micronesians are closely related to the Jōmon pottery makers, the people who inhabited prehistoric Japan. Even recent work on mitochondrial DNA shows that Polynesians are closer to the remaining preagricultural people of the Philippines than to anyone on the Asian mainland.

If Austronesian has its roots in mainland Southeast Asia and the modern Polynesians have their biological roots in post-Pleistocene Japan, then the movement into the Pacific has to include an account of how the people who came from one place acquired a language that arose in another. Although that idea may sound implausible at first, it is not at all impossible.

C. Loring Brace
Museum of Anthropology
University of Michigan
at Ann Arbor

Bellwood replies:

I agree that Jōmon Japanese, Polynesians and Micronesians might have shared a common origin. But why in Japan instead of coastal China? Biological anthropologists, including Professor Brace and others who have claimed an equally unlikely origin for Polynesians in Pleistocene Melanesia, are obliged to do their calculations without the benefit of an absolutely crucial set of data: there are no large and measurable skeletal series from around 4,000 years ago in the Philippines, eastern Indonesia and coastal China south of the Yangtze River. I claim those areas were the overall homeland region. Have the biological patterns in south China and Southeast Asia really been frozen for the past 4,000 years? Or have populations there changed over time, just as they have in other regions, such as Japan and Melanesia?

Overlooked among the Ions

I would like to rectify an omission in my recent article, "Focused Ion Beams" [Scientific American, October 1991]. While discussing work on optoelectronic devices with focused ion beams, I neglected to mention an important participant. Joe Puretz, who was then a student at the Oregon Graduate Institute, was instrumental in the success of the work and, with Richard DeFreez, did much of the experimental design, execution and analysis. He was also one of the primary authors on many of the subsequent papers. I profoundly regret that I did not give Dr. Puretz the credit he deserves; his contribution to the success of that work was certainly greater than my own.

Jon Orloff
Department of Applied Physics and
Electrical Engineering
Oregon Graduate Institute
of Science & Technology

ERRATA

Photo credits for figures appearing on page 45 of the October 1991 issue were omitted. Figure *e* was provided by Nick Butterfield of Harvard University. Figure *f* was provided by Richard Jenkins of the University of Adelaide.

50 AND 100 YEARS AGO

FEBRUARY 1942

"In the kind of war we are fighting today civilian protection is necessary because this is an 'all-out' war, a 'total' war, an 'everybody's' war—and there's nothing new about it. It is as old as mankind. In fact, we have Mr. Schicklegruber's statement for it that one objective of this kind of a war is 'the disappearance of the vanquished people from the stage of history.' That's why we must consider civilian protection. That's why we are faced with the necessity of perfecting organizations to minimize the effects of air-raid damage, to prevent hysteria, and above all to save civilian lives."

"A rocket for military use might derive its power from the combustion of alcohol or gasoline in combination with liquid oxygen. The motor is merely a combustion chamber provided with a nozzle for the escape of the exhaust gases. A control chamber could be equipped for wireless control of the rudder. Nothing very formidable in all this, though a rocket is not cheap as compared with a shell.

"Now as to the various possible military uses of rockets: Today's three-inch anti-aircraft shells are not very effective and do not reach the required altitude. The German bombers were able to reach London again and again in spite of a tremendous concentration of anti-aircraft guns. But a rocket starts from the ground with zero velocity and accelerates as long as its fuel lasts. One thus could readily be designed to reach 30,000 or even 40,000 feet. Perhaps there is here a formidable weapon against enemy bombers? The rocket played a part in destroying Napoleon's invasion fleet against England. Perhaps large rocket shells could become a species of long distance artillery?

"Finally, the rocket, inefficient as it is for propulsion at the present speeds of the airplane, could be used to give an enormous thrust to planes at take-off and thus permit our long distance bombers to be greatly overloaded."

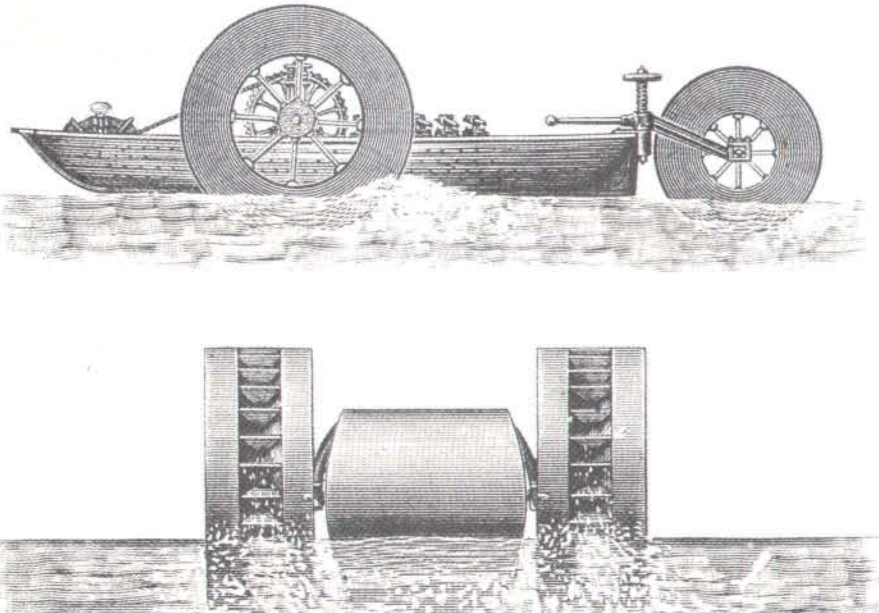
SCIENTIFIC AMERICAN

FEBRUARY 1892

"Professor R. L. Garner proposes to visit Africa, with such appliances for a residence among the gorillas as will enable him to become acquainted with their speech. He intends to occupy a large and strong iron cage, in which he can be safe from the attacks of the powerful animals, while he listens to their remarks and preserves them by the phonograph. Professor Garner thinks that he will be able to ascertain the views of leading gorillas with less difficulty and more precision than is possible in the case of some distinguished persons who speak with great facility on topics of vital interest."

"Henry Wilde, Fellow of the Royal Society, has come to the conclusion that the outer shell of the earth and the great mass within rotate somewhat independently of each other. The interior portion, still in a liquid condition, he conceives as continuing to revolve about the axis which our planet had in its infancy. Somehow, in the great cataclysm in which the moon was thrown off from the earth, the crust of our globe was, he thinks, skewed over to one side about twenty-three degrees. Mr. Wilde constructs a machine, consisting of one sphere within another slightly larger one, both converted into magnets by coils of wire encircling them. Upon those portions of the shell which correspond to the oceans he attaches magnetized sheet iron. He makes the inner and outer spheres rotate on axes $23\frac{1}{2}$ degrees apart. Finally, for test purposes, he provides for temporarily fixing a magnetic needle at any point on the surface of the globe. With this ingenious apparatus, he declares he can reproduce every known variation of intensity and direction in terrestrial magnetism of which he can find a record; and, what is the convincing feature of his experiment, the real magnetic history of all parts of the world for the last four centuries, so far as he can learn it, is actually repeated in the minutest details when the inner sphere is made to fall behind the outer one, in their revolution, at the rate of $22\frac{1}{2}$ minutes of an arc annually!"

"Mr. Gustave Trouvé has always been struck with the great difference observed between the speeds of locomotives and ships. The great kinematic inferiority of ships he attributes to the enormous resistance offered to them by the water. But do the two functions of sustenation and propulsion each necessitate, in reality, its own particular organs? It was in order to solve these questions that Mr. Trouvé designed the apparatus of which a side and front view is given in the figure."



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SCIENCE AND THE CITIZEN

Early Arrivals

Scientists argue over how old the New World is

It's embarrassing, really. The quincentennial of Columbus's discovery has naturally aroused curiosity about the people who really discovered the New World, whose descendants were on the shore watching as Columbus's ships approached. Just when and how did the Ur-Americans arrive?

Only a decade or so ago most archaeologists would have offered a simple answer: humans trekked into the New World by crossing a land bridge from northeast Asia about 12,000 years ago and quickly spread southward. In recent years, however, a growing body of evidence—primarily archaeological but also derived from genetic and linguistic analyses—has suggested that humans arrived at least several thousand and possibly tens of thousands of years sooner. "This puzzle isn't close to being solved," says Stephen L. Zegura, an anthropologist at the University of Arizona.

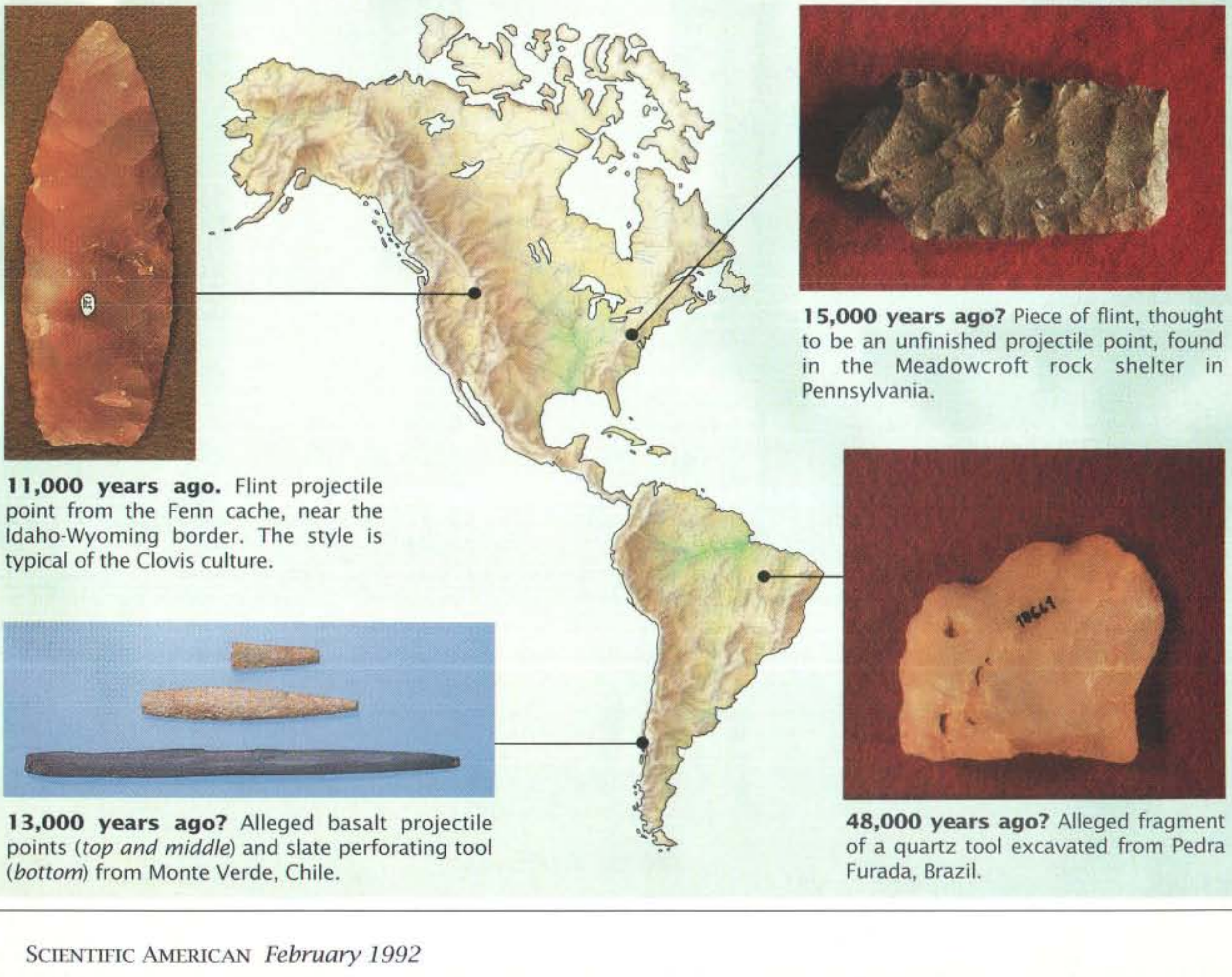
The old theory, which is often called the Clovis scenario, dates back to the 1930s, when archaeologists discovered a site in Clovis, N.M., containing fluted stone blades that appeared to have served as knives or spearpoints. Since then, Clovis points have been unearthed at locations throughout the Americas. The most ancient of these artifacts are about 11,000 years old.

Most archaeologists came to believe that these big-game hunters, called the Clovis people, were the first Americans and that their ancestors had migrated from Asia perhaps 1,000 years earlier, during the waning years of the Ice Age. Much of the world's water was still locked up in ice, and Siberia and Alaska were linked by a stretch of land known as Beringia.

In the mid-1980s a modified version of the Clovis scenario began winning converts. The theory was proposed by Christy G. Turner II of Arizona State University, an expert on teeth; Joseph H. Greenberg of Stanford University, a linguist; and Zegura, who specializes in genetics. Based on their analyses of languages, genes and teeth, the researchers concluded that the descendants of all modern Native Americans arrived in three distinct waves. The workers suggested that their data, although not confirming the Clovis time frame, were consistent with it.

While Turner and his colleagues were

How Long Ago Were People Living in the New World?



11,000 years ago. Flint projectile point from the Fenn cache, near the Idaho-Wyoming border. The style is typical of the Clovis culture.

15,000 years ago? Piece of flint, thought to be an unfinished projectile point, found in the Meadowcroft rock shelter in Pennsylvania.

13,000 years ago? Alleged basalt projectile points (*top and middle*) and slate perforating tool (*bottom*) from Monte Verde, Chile.

48,000 years ago? Alleged fragment of a quartz tool excavated from Pedra Furada, Brazil.

promulgating this three-migration, neo-Clovis theory, support was accumulating for archaeological sites apparently occupied long before the Clovis culture began. The two most widely accepted pre-Clovis sites are at Monte Verde, Chile, and Meadowcroft, Pa.

Monte Verde's chief investigator, Tom D. Dillehay of the University of Kentucky, has reported finding stone tools, the remnants of a hut and other signs of a camp occupied 13,000 years before the present. He has also tentatively identified some stone fragments as 33,000-year-old tools. The head of the Meadowcroft excavation, James M. Adovasio of Mercyhurst College, has reported uncovering stone tools, animal bones and charcoal at least 15,000 years old and possibly 19,000 years old.

The most spectacular—and controversial—alleged pre-Clovis site is an ancient rock shelter in Pedra Furada, Brazil, excavated by the French archaeologist Niède Guidon of the Institute of Advanced Social Science Studies in Paris. Guidon claims to have uncovered stone tools and other human by-products at the site that could be 48,000 years old.

Other alleged pre-Clovis sites of note include Bluefish caves in Canada's Yukon Territory, where investigators say they found bone tools 25,000 years old; Taima-taima in Venezuela, which has yielded a seemingly butchered mastodon bone 13,000 years old; and Orogrande cave in New Mexico. Orogrande's excavator, Richard S. MacNeish of the Andover Foundation for Archaeological Research, claims to have found a clay hearth with a human palm print 28,000 years old and stone tools as much as 10,000 years older.

Meanwhile several geneticists have provided corroboration for pre-Clovis migrations. Zegura, who with Greenberg and Turner developed the neo-Clovis theory, now thinks humans could have arrived anywhere from 15,000 to 30,000 years ago and that they might not have come in three waves but in a single group that divided later. Luigi L. Cavalli-Sforza of Stanford, after comparing the DNA of Native Americans with that of Asians, has concluded that they diverged from one another in Asia some 30,000 years ago.

The same date has been obtained by Douglas C. Wallace of Emory University, who analyzed a type of DNA inherited solely from the mother. Wallace's team asserts that virtually all modern Native Americans are descended from four women of Asian lineage who lived approximately 30,000 years ago—give or take about 10,000 years. If these women were part of a band of migrants into the New World, Wallace and his colleagues note in the January 1992 issue of *Genetics,* "this time range would suggest that the Americas were colonized before the dates associated with the oldest...Clovis lithic artifacts."

The results of Wallace's group have been challenged by another team led by Richard H. Ward of the University of Utah and Svante Pääbo of the University of Munich. Ward and Pääbo failed to find the four distinct maternal lineages reported by Wallace's group. Instead they trace modern Native Americans back to a single woman living some 60,000 years ago—probably in Asia. They say it is impossible to know, based on the genetic evidence gathered thus far, when this woman's descendants crossed into the New World.

New data may help resolve this issue. Wallace hopes a detailed genetic survey of people in northeast Asia will establish more precisely when and where the proto-Americans began to diverge. William W. Hauswirth of the University of Florida is studying DNA extracted from 91 skulls up to 8,000 years old found in a Florida bog in 1984. The study should help establish just how fast DNA evolves.

The pre-Clovis view is getting support from at least one linguist. In 1990 Johanna B. Nichols of the University of California at Berkeley argued in the journal *Language* that 12,000 years is simply not enough time to generate the extraordinary diversity of languages among Native Americans. If one assumes that the Americas were populated by a single group of migrants speaking one language, then they must have arrived from 50,000 to 60,000 years ago; a dozen or so waves of migrants speaking different languages could have produced the same result in 30,000 to 40,000 years, Nichols argues.

But Merritt Ruhlen, an unaffiliated linguist who is closely associated with Greenberg and the three-migration theory, disagrees. While asserting that one cannot base chronologies on language alone, he insists that the Clovis time frame can accommodate Native Americans' linguistic diversity.

Other proponents of the Clovis scenario have attacked the validity of the pre-Clovis sites. In an upcoming issue of *American Antiquity,* Kenneth B. Tankersley of the Illinois State Museum suggests that coal contaminants have distorted the carbon 14 dates from the Meadowcroft site. C. Vance Haynes of the University of Arizona, a leading authority on the Clovis culture, thinks the "tools" from New Mexico's Orogrande cave are just broken rocks. While acknowledging the apparent validity of the Monte Verde site, he argues that it represents only a single, odd data point. "It needs duplication," he says.

The most adamant Clovis adherent is Thomas F. Lynch, an anthropologist at Cornell University. The pre-Clovis claims, he declares, are the products of sloppy standards and wishful thinking. "People want to believe in this," he says, "just like they want to believe in cancer cures." He predicts that all the alleged pre-Clovis habitats will eventually be discredited, just as many others have been over the past 50 years.

Lynch and others also argue that more than 14,000 years before the present both the Bering land bridge and Canada would have been buried in ice and so impassable. If people did somehow make the journey 15,000 or 20,000 or 50,000 years ago, moreover, why haven't they left more signs?

Alan L. Bryan of the University of Alberta, who advocates pre-Clovis scenarios as fiercely as Lynch attacks them, retorts that people could have paddled down the coast of North America in primitive boats, perhaps as early as 100,000 years ago, instead of traversing the continent's ice-ridden interior. When the Ice Age ended, the sea rose and concealed their coastal habitats.

Even more radical migration routes have been suggested by Robson Bonnichsen, who heads the Center for Study of the First Americans at Oregon State University. Humans might have crossed from Australia to South America either via Antarctica, he suggests, or by island-hopping across the Pacific. Guidon, the excavator of the Pedra Furada site, says a transatlantic crossing from Africa cannot be ruled out either. "We need to think of different ways to reach the New World than just by Beringia," she says.

David J. Meltzer, an anthropologist at Southern Methodist University, agrees that more complex population scenarios might be required to make sense of the data. He notes that some people might have arrived in the New World very early—accounting for the extremely old artifacts found by Guidon and others—but then died out, leaving no genetic or linguistic legacy.

All this uncertainty has created headaches for Dennis J. Stanford, who as director of the paleo-Indian program at the Smithsonian Institution is designing an exhibit on the peopling of the New World. Stanford says that he plans to hedge his bets by presenting a number of different hypotheses. The exhibit will also include origin myths of Native Americans themselves, most of whom insist their ancestors have always lived in the New World. "Of course," Stanford points out, "our ideas may be myths, too." *—John Horgan*

A Confusing Little Ice Age

Between 1500 and the end of the 19th century, Europe experienced an extended episode of cold known as the Little Ice Age. During that time, glaciers advanced, the Dutch canals froze over and harvests became erratic. At the fall meeting of the American Geophysical Union last December, researchers reported some clever detective work that shows what the weather was like during the Little Ice Age and how it has changed since then. The recent evidence exposes a complicated pattern of climatic change, a finding with considerable implications for those researchers trying to predict the effect of human activity on global environment.

One technique for inferring ancient weather simply involves measuring the temperature of a hole bored in the earth's surface. Surface temperatures seep very slowly through rock; the temperature roughly 300 meters down reflects surface temperatures during the Little Ice Age. "These are direct temperature measurements," notes Henry N. Pollack of the University of Michigan.

So far most of the borehole studies have been done in North America. Pollack reports these boreholes generally show that the region has been growing warmer during the past century, after a period of cooling during the 19th century. But the amount of warming varies considerably from place to place, and some locations have actually grown colder.

Equally ambiguous are climate data obtained from cores of glacier ice. Ice cores yield very precise dates because it is possible to count each year's snowfall, and the relative abundance of oxygen isotopes in the ice makes it possible to infer the temperature when the snow accumulated.

Climate models predict that temperature changes should show up most strongly at high latitudes. Yet Richard B. Alley of Pennsylvania State University finds that the Little Ice Age was "very little" in Greenland—so little that it cannot clearly be distinguished from the random error in his measurements. Similarly, Lonnie G. Thompson of Ohio State University says ice cores from the Antarctic Peninsula reveal no sign of cooling during the Little Ice Age.

At the same time, though, Thompson sees significant temperature fluctuation recorded in mountain glaciers at low latitudes. He speculates that worldwide climate changes may vary according to altitude as well as latitude. Oceanic effects also complicate the story: Glen T. Shen of the University of Washington finds indications in Pacific coral that the waters of the East Pacific were actually warmer during the Little Ice Age than now.

Adding to the confusion, the Little Ice Age probably varied not only in space but also in time. Malcolm K. Hughes of the University of Arizona uses tree rings as weather recorders. He describes the Little Ice Age as "a set of clusters of relatively cold winters" but adds that even during that period not every year was necessarily a cold one. By combining tree-ring data from around the globe, Hughes perceives abrupt environmental changes and climate cycles that switch on and off. "We're starting to see the first hints of how climate really works," he says. *—Corey S. Powell*

Night Heat

Sulfate pollutants may slow daytime warming

The threat of greenhouse warming has led scores of biologists to attempt to judge how agriculture, forestry and natural ecosystems are likely to be affected by higher temperatures. A mammoth international study of more than four decades of temperature trends in the U.S., the Soviet Union and the People's Republic of China now suggests researchers have been wasting their time.

Virtually all the assessments of warming to date, including that of the United Nations Intergovernmental Panel on Climate Change, have assumed that nighttime and daytime temperatures would increase equally as greenhouse gases accumulate in the atmosphere. But the new study, led by Thomas R. Karl of the National Climatic Data Center in Asheville, N.C., shows that in the Northern Hemisphere the temperatures have increased mainly at night. Nighttime warming is relatively benign for plants, limiting dehydration and other damage done by daytime heat and reducing harm from cold at night. "This is very significant—it means you don't get many of the adverse effects on agriculture," says Philip D. Jones of the Climate Research Unit at the University of East Anglia in England.

Global average temperature has certainly increased over the past century—by between 0.3 and 0.6 degree Celsius. But Karl's study, published in *Geophysical Research Letters,* indicates that most of the increase turns out to be the result of higher daily minimum temperatures; in other words, nights are getting warmer. Daily maxima, on the other hand—generally recorded during daylight hours—have hardly increased at all in the U.S. and China and only a little in the Soviet Union.

Data collected by Karl a few years ago indicated that daily temperature ranges in the U.S. have been decreasing, and some critics of warming projections—notably Patrick J. Michaels of the University of Virginia—used that information to argue at the time against accepting warming predictions. But it was unclear then whether the effect was peculiar to North America.

By including the Soviet Union and much of China in the analysis, Karl seems to have convinced researchers that most of the warming of the Northern Hemisphere this century is a nighttime phenomenon. Karl's study combined data from 744 recording stations spread over 40 percent of the Northern Hemisphere's landmass. The U.S. data in Karl's study go back as far as 1901; the Soviet data go back to 1936 and the Chinese to 1951. The U.S. data were corrected for increasing urbanization.

The new findings point to serious failings in the computer-based climate models now used to study the greenhouse effect, which do not predict substantial differences between nighttime and daytime warming. The nighttime warming signal is "so big that it deserves some physical explanation," Karl says. "Either the models are not properly predicting day effects versus night effects, or the signal we see is something other than greenhouse warming."

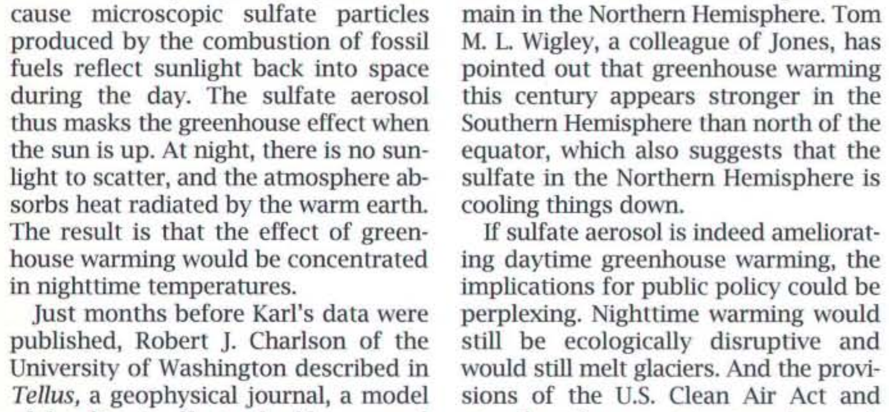
There is a theory that could explain the anomaly, although researchers caution that it is as yet unproved and that other unknown effects might be at work. Warming might be more pronounced at night, Jones explains, because microscopic sulfate particles produced by the combustion of fossil fuels reflect sunlight back into space during the day. The sulfate aerosol thus masks the greenhouse effect when the sun is up. At night, there is no sunlight to scatter, and the atmosphere absorbs heat radiated by the warm earth. The result is that the effect of greenhouse warming would be concentrated in nighttime temperatures.

Just months before Karl's data were published, Robert J. Charlson of the University of Washington described in *Tellus,* a geophysical journal, a model of the climate effects of sulfate aerosol that correctly predicts masking of greenhouse warming in the Northern Hemisphere. "It is tempting to make the link to sulfate aerosol," Karl says. "I am personally not yet convinced, but I think a lot of work will be done on this."

Sulfate aerosol might also have an effect by seeding the formation of clouds. Some satellite observations do indicate the world is becoming more cloudy. But it is unclear exactly what the effects of clouds are, and the precise relation to sulfate aerosol is unknown, Charlson says. The case for clouds masking daytime warming, as opposed to aerosol directly, is far from established.

Still, other statistics seem to support some role for sulfates. According to Jones, data from the Sudan also show nighttime warming, suggesting the effect does extend over much of the Northern Hemisphere. Figures from Australia, in contrast, show warming there is more evenly distributed between night and day. That fits nicely with the sulfate aerosol theory, Karl says, because 90 percent of the sulfates released into the atmosphere remain in the Northern Hemisphere. Tom M. L. Wigley, a colleague of Jones, has pointed out that greenhouse warming this century appears stronger in the Southern Hemisphere than north of the equator, which also suggests that the sulfate in the Northern Hemisphere is cooling things down.

If sulfate aerosol is indeed ameliorating daytime greenhouse warming, the implications for public policy could be perplexing. Nighttime warming would still be ecologically disruptive and would still melt glaciers. And the provisions of the U.S. Clean Air Act and steps by other countries to reduce pollution from fossil fuels may have an unintended effect. If the sulfate theory is right, Karl notes, the decrease in sulfate emissions might hasten global warming. *—Tim Beardsley*



DAILY MINIMUM TEMPERATURES, usually the nighttime low, have risen significantly over much of the Northern Hemisphere during the past 40 years. At the same time, the change in daily maximum temperatures has been small.

New Whoof in Whorf

An old language theory regains its authority

Linguistic relativity—the idea that the language one speaks shapes the world one sees—was framed in the 1940s, embraced in the 1950s and seemingly discredited by rigorous tests in the late 1960s. Yet some researchers say it is worth another look, arguing that although the particularities of language may not control the mind, they may influence it in subtle ways.

Linguistic relativity is better known as the Whorf Hypothesis, after Benjamin Lee Whorf, an insurance man and part-time linguist who popularized it. "We cut nature up, organize it into concepts, and ascribe significances as we do, largely because we are parties to an agreement to organize it in this way," he wrote. "All observers are not led by the same physical evidence to the same picture of the universe, unless their linguistic backgrounds are similar, or can in some way be calibrated."

Whorf's idea was eagerly adopted by cultural anthropologists intent on explaining individuals as the products of culture and culture as autonomous of biology. Most linguists, however, regarded the hypothesis as speculative and preferred theories that emphasized matters common to all languages. The universalists seemed to win the day in 1969, when Brent Berlin and Paul Kay of the University of California at Berkeley disproved that color perceptions varied among cultures. They found that all languages added color terms according to a strict pattern. After some refinement, they now say languages having two terms group red, yellow and white under one and green, blue and black under the other. Those having three group red and yellow together, as opposed to white. Languages add subsequent terms through successive divisions of the remaining categories.

Ridicule was added to such refutations when the most widely repeated Whorfian anecdote was debunked. Whorf had asserted that Eskimos use many distinct words in place of the one English word "snow." He concluded that an Eskimo and an Anglo would perceive the same snowdrift differently because they pigeonhole the concept into different lexical grids. But Laura E. Martin, an anthropologist at Cleveland State University, traced the story to its sources and found that Whorf had exaggerated the number of Eskimo snow roots while understating the number in English: slush, powder, blizzard and so forth.

Mistakes were made, admits John J. Gumperz, a linguistic anthropologist at Berkeley. But Whorf had his finger on part of the truth, he maintains, and workers are now revising relativist ideas in the light of acknowledged language universals. Gumperz, who helped to organize a conference on the subject last summer, says linguists are particularly interested in indexicality—cultural conventions on how meanings of words vary with the circumstances of use. "We" in English, for example, means one thing in the sentence, "We get our alphabet from the Phoenicians," and another in Queen Victoria's famous statement, "We are not amused."

Another area of investigation concerns uses of language that are not centered in an individual—deliberations of information that no one person possesses at any one time. Such out-of-body thinking, as it were, can be seen in the rhyming mnemonic devices of oral cultures and in writing, which enables one to conduct an elaborate discourse with oneself. Habits inculcated by reading and writing often leave marks on utterances—for example, by inducing a person to talk like a book.

But is there nothing more striking than this to put beside the flights of fancy of the early Whorfians? Stephen C. Levinson of the Max Planck research group for cognitive anthropology told the conference of collective work suggesting that spatial conceptualization is not universal. Certain Australian languages, for example, are devoid of relative terms for space—"in front of" or "beside"—but instead refer to an absolute frame of reference—"north of," "south of." This system has sweeping implications because it requires speakers wishing to report a scene to memorize it with its cardinal directions.

Spatial distinctions of particular languages are mastered very early in life, says Melissa Bowerman, also of the Max Planck group. She cites studies of Korean children as young as 18 months who understand exotic distinctions that their language makes. For example, they distinguish between "on tightly" and "on loosely," as in "He put the lid (tightly) on the jar, which is (loosely) on the table." Developmental psychology has assumed, since the classic experiments of the Swiss psychologist Jean Piaget, that children develop concepts of space first and then apply language to them. But if, as Bowerman believes, the order is sometimes reversed, then intellectual development may itself be conditioned by culture. "I think Bowerman's results are very impressive," Kay says.

But he cautions against exaggerating the contrast between languages. Languages that make unique distinctions, he says, usually make the more familiar ones as well. Western languages, for example, have been characterized as representing time in linear terms, in contrast to the cyclical terms of many non-Western languages. "But Western languages have days of the week, months of the year, the seasons, which are cyclical schemata," he says, just as non-Western languages have linear schemata. "Whorfians," Kay points out, "have sometimes tended not to look at the diversity that exists within each language." *—Philip E. Ross*

The End of Clumpiness?

Over the past decade or so, astronomers have found ever larger bunches of galaxies—from clusters and superclusters to immense individual features such as the Great Wall—surrounded by ever larger voids. Perhaps the most troubling (or exhilarating, depending on one's theoretical bent) aspect of the trend has been that no end seemed in sight. The bigger the chunk of sky mapped by astronomers, the bigger the structures they found. It was as if topographers mapping a new continent's terrain kept finding taller mountains and deeper canyons as they broadened the scope of their search.

But a new, deep-space galaxy survey being conducted by four U.S. astronomers seems to have bucked the trend toward clumpiness, at least temporarily. "We may finally have gotten to the point where things begin to look smooth," says Augustus Oemler of Yale University. Oemler and his colleagues—Stephen A. Schectman of the Carnegie Institution, Robert Kirshner of Harvard University and Paul Schecter of the Massachusetts Institute of Technology—are using a 2.5-meter telescope at Las Campanas Observatory in Chile.

In some respects, their survey is similar to the one done two years ago by a group at the Harvard-Smithsonian Center for Astrophysics that revealed the Great Wall—a sheet of galaxies several hundred million light-years long. Both groups determine the distances of galaxies by measuring the degree to which their light is reddened by their motion away from the earth. Both groups also map deep, wedge-shaped slices of the universe rather than broad, shallow swaths. But whereas the Harvard-Smithsonian workers measure the redshifts of galaxies one at a time, the group at Las Campanas can gather many simultaneously.

This feat is made possible by the telescope at Las Campanas, which has an unusually broad field of view and special optical-fiber detectors designed by Schectman. The telescope focuses on a patch of sky containing as many as 100 galaxies; each galactic image feeds into its own fiber and then into a spectrometer that measures its redshift.

The slices of the survey done at Las Campanas also extend from one to two billion light-years away from the earth, or one tenth the radius of the observable universe. That is three to four times deeper than the region mapped by the Harvard-Smithsonian group.

So far the team at Las Campanas has mapped the positions of more than 6,500 galaxies in several slices of sky. Although the survey has revealed clusters and voids comparable in size to the Great Wall, it has found nothing larger. "Our preliminary look at the data doesn't suggest there are any hyperstructures," Kirshner says.

The researchers point out, repeatedly, that the survey's results are still tentative. They say they will feel more comfortable about drawing cosmological conclusions from their survey after mapping at least 5,000 more galaxies and subjecting them to a rigorous statistical analysis rather than just a visual scan. On the other hand, Schecter notes, "The eye is a very good perceiver of objects."

Tentative or not, the group's data are certain to relieve many cosmologists. The clumpiness trend had created not only a dwindling supply of superlatives but also severe theoretical problems. The biggest puzzle was the sharp contrast between the galaxies' clumpiness and the exceptional smoothness of the cosmic microwave radiation, which is thought to be the faint afterglow of the big bang.

But theorists will still be hard-pressed to explain how the once smooth universe gave rise to features as vast as the Great Wall. "People are already having difficulty with the structures that are there," Schecter observes. "This just means that things may not get any worse." *—John Horgan*

Shear Bliss

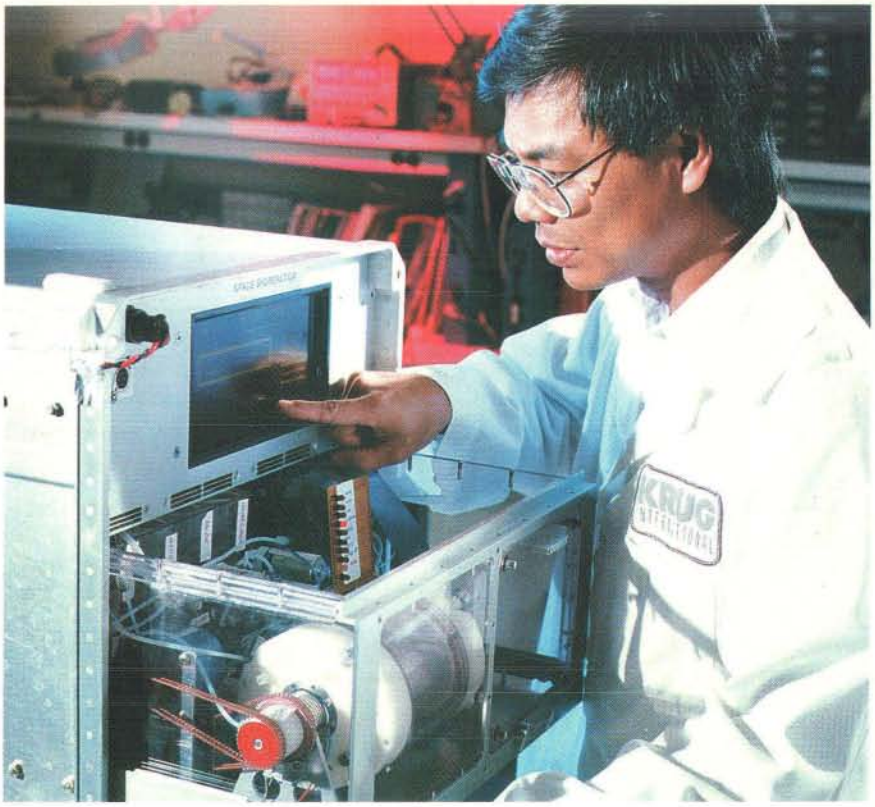
A bioreactor grows cells that resemble real tissue

The National Aeronautics and Space Administration likes to make the most of things when one of its gizmos turns out to have some use here on earth. And it is bursting with pride over the "rotating wall bioreactor," a device that allows human cells to be grown in such a way that they take on characteristics of those in normal tissues. It could hasten the day when replacement tissues or even whole organs for transplantation can be grown in culture.

The idea behind the bioreactor is a case of pure serendipity that has other researchers asking: "Why didn't I think of that?" Tinh Trinh and David A. Wolf of the Johnson Space Center in Houston had set out to find a way to protect delicate cell cultures from the high shear forces generated in liquid culture media during launchings and landings of the space shuttle. At the same time, they had to provide sufficient nutrients and oxygen to the living cells.

Their solution was to add an inner cylinder to a conventional "roller bottle" bioreactor. Cells are suspended in a liquid culture medium between the walls of inner and outer co-rotating cylinders. That way the layer of medium between the walls rotates as a solid body, and cells are not affected by shear as the liquid moves. Cells fall constantly but never get anywhere because of the rotation. The inner wall is porous, allowing nutrients and gases to diffuse in and out. Add a few seals, variable-speed motors and ports for sampling, and that's it. Trinh, Wolf and their colleague Ray P. Schwarz received a patent on the invention last year.

To their surprise, the researchers found that on terra firma, cells grown in the low-shear environment developed to a more advanced stage than those grown in conventional cultures. They form three-dimensional structures several millimeters across that one researcher likens to caricatures of normal tissue. According to Glenn Spaulding, manager of the space biotechnology program at Johnson, the bioreactor's low-shear conditions allow different types of cells to grow in close contact with one another. That allows them to interact chemically, which probably explains why they go much farther toward differentiating into tissues than cells in other cultures.



ROTATING CELL CULTURE DEVICE developed by NASA researchers allows cells to differentiate into specialized forms. Photo: NASA Johnson Space Center.

Researchers have been quick to find uses for the apparatus. Mary Lou Ingram of the Huntington Medical Research Institutes in Pasadena, Calif., is using the bioreactor to grow convincing gliomas, deadly brain cancers, so that patients' lymphocytes can be "trained" outside the body to attack the tumor before the cells are implanted in the brain.

Mary Pat Moyer, a microbiologist at the University of Texas Health Science Center at San Antonio, is growing lung and liver cells that produce enzymes and other molecular markers normally seen only in intact tissue. Cells from the small intestine, she says, group together to form structures resembling crypts of Lieberkühn, tubular glands of the intestinal mucous membrane that degenerate in conventional cultures. Molecular indications of blood vessel formation also appear in her cultures.

Another researcher, Philip C. Johnson of the University of Texas Health Science Center at Houston, is growing colon-lining cells and has preliminary evidence that the system will support the growth of Norwalk virus, an important agent of disease that will not propagate in standard cultures. Lisa Freed of Harvard University is using the bioreactor to grow pieces of cartilage bigger than can be grown in other systems. And J. Milburn Jessup of New England Deaconess Hospital in Boston is culturing colon cancer cells that resemble real tumors and bear cell-surface antigens believed to be important in metastasis.

Researchers are eager to see how the bioreactor performs in its intended environment—the microgravity of near-earth orbit where the stresses on cells should be even smaller than they are on the earth. A bioreactor containing plastic beads was flown on the space shuttle late last year, and according to Spaulding preliminary data confirm computer simulations of flow patterns.

Jessup, for one, looks forward to the day when bioreactors on the space station will be used to grow replacement human organs for transplantation. Why should weightlessness help, when humans normally develop in full gravity? Jessup says the reason is that an embryo builds its own scaffolding as it grows, but attempts to mimic organ development must manage without the scaffolding. "I think it will be economically feasible 20 years from now," he predicts.

That projection is too starry-eyed for NASA: Spaulding prefers to emphasize the advantages of research in space and suggests that microgravity might make it possible to understand delicate processes like the growth of nerve cells. Still, he is not complaining about researchers' enthusiasm for their new low-tech tool. *—Tim Beardsley*

Abyssal Proposal

Are the ocean depths a safe place for sewage sludge?

Several thousand meters under the waves, vast, flat valleys stretch across the ocean floor. Called abyssal plains, these regions cover 80 percent of the underwater world. Some are known to be periodically stirred by violent deep-sea storms; others are thought to be relatively quiescent. And although life seems unlikely at such depths and pressures, these rich, lightless plains are home to creatures, many rare and unusual, from every phylum.

The abyss may become home to human waste as well. Some scientists at Woods Hole Oceanographic Institution (WHOI) have proposed conducting an extensive experiment to study the fate and biological effects of depositing large volumes of materials such as treated sewage, or sludge, in the deep ocean. Arguing that landfill space is running out and that contamination of groundwater poses a growing threat to human health, these researchers say abyssal plains may safely serve as repositories for sludge.

At the very least, the oceanographers say, scientific research is needed to determine the feasibility of such an approach. "We may find out that this is a terrible idea," comments John W. Farrington, associate director for education at WHOI. But, he adds, "I get very worried when we foreclose on options before we have a long-term understanding of them. We should have an experiment to evaluate sludge on the bottom."

Other scientists are opposed to the idea. "I think that that is a totally inappropriate and scandalous proposal," exclaims George M. Woodwell, director of the Woods Hole Research Center. "Further studies on how to drive ocean systems into impoverishment are certainly not needed."

The proposal, which is the outcome of a workshop held at WHOI in January 1991 and which will be, in part, the subject of a congressional hearing early this year, comes at a time when sludge dumping in the seas is dropping off. Under the Ocean Dumping Ban Act of 1988, all disposal of municipal sludge ceased by the end of 1991—except for New York City, which will dump until June, despite high fines.

"The coastal areas are weaning themselves of ocean dumping," says Sarah L. Clark, a scientist at the Environmental Defense Fund. "The environmental community is working toward making sludge a valuable resource. By opening up a new avenue of disposal, that goal would be much harder to reach."

Clark says a large percentage of sludge could find what is termed "beneficial reuse" as fertilizer or topsoil. Indeed, according to the Environmental Protection Agency, such reuse is already the fate of almost half of U.S. sludge. The agency is soon expected to issue additional limits on the amounts of contaminants allowed in sludge, accelerating a national trend toward cleaner forms of the waste.

Sludge is a small portion of the ocean waste stream, according to the EPA. Dumping industrial waste ceased in 1988, but dredged materials make up more than 90 percent of the ocean-bound waste: some 60 to 80 million cubic yards of such wet material are dumped at up to 110 sites along the coast annually. The EPA was expected to issue new regulations controlling dredge spoil—often laden with heavy metals—in 1991; the guidelines are now expected in late 1992. By targeting sludge, some WHOI scientists are "focusing attention on the waste stream that needs the least attention," Clark says.

ORGANISMS, including brittle stars, live on the deep ocean floor. Photo: J. Frederick Grassle.

In addition, Clark and others say dumping could have adverse effects. They point to recent studies of the ocean dump site receiving New Jersey and New York sludge. Since 1986, more than 38 million tons of sludge have been disposed of at Site 106, so called because it is situated that many miles southeast of New York City. Scientists have found that bottom-dwelling communities there have been altered: large scavengers have moved in, and some species not usually found in the area are increasing. Contaminants have also been identified in the food chain.

Supporters of the proposed experiment, however, counter that deep-sea emplacement could solve a serious problem and that any biological effects would be limited and would not threaten human health. "If you had clean sludge, you could put it anywhere, but the fact is that we don't have clean sludge," says Judith E. McDowell Capuzzo, a biologist at WHOI. "The important aspect of the abyssal plains is the inability of material to be transported back to man."

As it now stands, the proposal would place one million tons of sludge per year for 10 years on the floor of the Hatteras Abyssal Plain in the Atlantic Ocean. Recent studies have described the transport of material into and out of the deep ocean, but researchers say these processes would not bring fecal bacteria or toxins back to humans. For example, studies of the circulation of radionuclides from Britain's Sellafield reprocessing facility have shown that the materials move from the coast, through the Irish Sea to the Arctic and then south toward the deep currents off North America—they do not return to shore.

Yet there remain many unknowns. The seasonal upwelling of the eggs of some deep-sea organisms indicates that materials can rise to the surface. In addition, "we know very little about the interchanges between coastal and deep ocean waters," says Martin V. Angel, a biologist at the Institute of Oceanographic Sciences in the U.K., who attended the WHOI workshop. "The environmentalists have perfectly valid criticisms: 'You don't know enough about shallow waters; why destroy both?'" Nevertheless, Angel adds, consigning a portion of deep ocean floor for dumping "is probably no worse than cutting down a woods in your backyard. We think the effects will be very localized."

Other researchers are concerned that contaminants have already reached the abyss and that their effects are undetermined. "There is some increase in pollutants in the deep ocean, and that is something we should be looking at," notes J. Frederick Grassle, director of the Institute of Marine and Coastal Sciences at Rutgers University. Industrial chemicals, such as PCBs, have been detected in some deep-sea organisms.

For many oceanographers, all the questions make for exciting research, as does the possibility of finding a solution for waste disposal problems. "The whole waste management issue has to be addressed in this country," notes Michael H. Bothner of the U.S. Geological Survey at Woods Hole. "We are running out of space." No studies of dumping on abyssal plains have been conducted.

But Woodwell says research does not have to be linked to sludge. He suggests that concerns about funding shortages for deep-sea research are behind the proposal, as well as a historical orientation. One of the proponents of the idea is Charles D. Hollister, a senior scientist at WHOI who has advocated the disposal of radioactive waste in the deep ocean. McDowell Capuzzo rejects these interpretations: "That doesn't drive my personal interest."

The congressional hearing will examine whether there should be a research exception to the ban. According to a staff member on the Merchant Marine and Fisheries Committee, a lot of pressure for the hearing has come from the forceful lobbying of a company, Amenco, and its attorney, Bart Fisher of the Washington, D.C.-based firm Patton, Boggs and Blow. Fisher represents an inventor, Alexander Copson, who has designed 1,000-ton bells that could lower sludge to the ocean floor without leakage. In contrast, the staffer notes, no scientists from WHOI have lobbied. Fisher says if legislation ultimately allows a permit, Amenco would conduct the deep-sea studies using private funding.

Whatever the outcome of the hearing and despite—or rather, because of—the uncertainties, many scientists support the experiment. "I wouldn't be persuaded unless it works," Angel says. McDowell Capuzzo adds: "Do you want to close out an option based on emotion or on a balance between science and societal needs?" *—Marguerite Holloway*

Life in the Fast Lane

Cheetahs are faster: over short stretches, they can sprint at 60 miles per hour. Racehorses get more attention at Derby time. But for high-speed, long-distance running, nothing beats the pronghorn, or American antelope. Some people have tried to clock pronghorns by following them in jeeps, says Stan L. Lindstedt, a physiologist at Northern Arizona University. According to the most reliable of those estimates, pronghorns can comfortably cover 10 miles in 15 minutes. "They certainly can maintain 45 miles per hour," Lindstedt says.

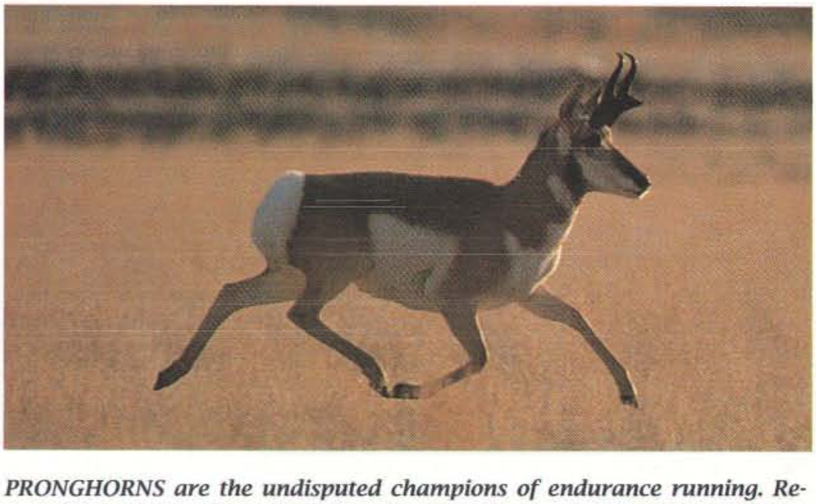
Lindstedt and his collaborators at Northern Arizona University, the University of Wyoming at Laramie and the University of Berne recently completed an analysis of what makes these souped-up herbivores so enduringly fast. As their report in *Nature* reveals, the pronghorn's secret is a series of small physiological and structural adaptations that allow it to consume oxygen with more than three times the expected efficiency. "We knew that we were either going to find something different with regard to their muscles or with regard to oxygen uptake," Lindstedt explains. "What we found was the latter. They're simply able to process a whole lot more oxygen than other animals their size."

As a rule, small mammals consume oxygen much more voraciously than large ones. One gram of shrew muscle uses up as much oxygen in a day as a gram of elephant tissue does in a month, the researchers point out. The rate of oxygen consumption is a critical limiting factor in any mammal's running performance: the faster the animal works, the more oxygen it consumes.

Beyond a certain point, the animal cannot burn the oxygen any faster. Further increments in performance then depend on anaerobic metabolism, which draws energy from the carbohydrate glycogen and produces lactic acid as a waste product. Peak anaerobic performance can be maintained only for a few minutes in most species.

To find the source of the pronghorn's endurance, Lindstedt and his colleagues fitted two young pronghorns with breathing masks and set them running on an inclined treadmill. (The reason for the incline, Lindstedt notes, was twofold: they did not want to risk hurting the animals with too high a speed, and the treadmill could not keep up with the pronghorns on a level surface.) When the pronghorns' oxygen use leveled off and lactic acid began to accumulate in their blood, the researchers knew they had found the animals' maximum oxygen consumption rate. That rate was triple the figure typical of animals with the pronghorn's body weight—indeed, it was more like that of a mouse.

Lindstedt's group then scrutinized pronghorn physiology and found several explanations for its aerobic capacity. "They have spectacularly large lungs" that are three times as large as those of comparably sized goats, Lindstedt says. The heart of a pronghorn is unusually large and its blood is rich in hemoglobin, which means that more oxygen can be delivered to the muscles in less time. The pronghorn's muscle cells are also densely packed with mitochondria, the structures that burn oxygen for fuel. Collectively, these adaptations allow the pronghorn to run for the long haul, the researchers assert. Both speed and endurance may be essential for helping pronghorns to escape from predators such as wolves. *—John Rennie*



PRONGHORNS are the undisputed champions of endurance running. Research into their unique physiology has now shown why. Photo: Comstock.

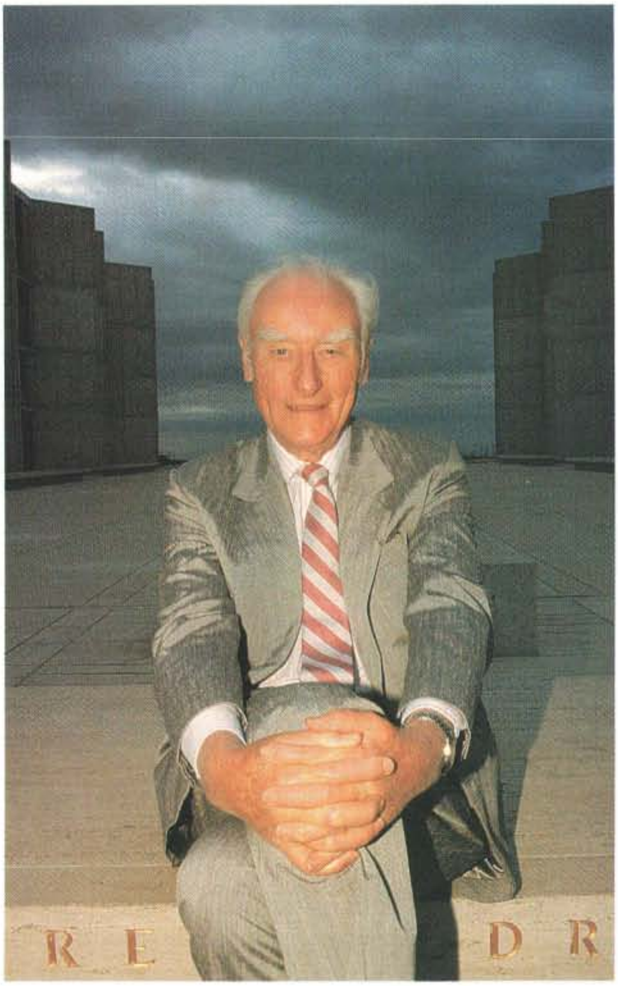
The Mephistopheles of Neurobiology

There is something almost preternaturally jolly about Francis Harry Compton Crick. His eyes and mouth curl up at the corners in a perpetual, wicked grin. His bushy white eyebrows flare out like horns. His ruddy face flushes even darker when he laughs, which he does often and with gusto. Crick seems particularly cheery when he is skewering some product of wishful and fuzzy thinking, such as my vain hope that we humans have free will.

Even an act as apparently simple as seeing, Crick points out in his utterly reasonable English accent, actually involves extensive neural computation. "The same could be said as to how you make a move, say, picking up a pen," he continues, plucking one from his desk and waving it before me. "A lot of computation goes on preparing you for that movement. What you're aware of is a decision, but you're not aware of what makes you do the decision. It seems free to you, but it's the result of things you're not aware of."

Crick's discourse—and Mephistophelian mien—befits his role as one of modern science's most pitiless reductionists. The 75-year-old theoretical biologist is famed for having unraveled with James D. Watson in 1953 the double-corkscrew structure of deoxyribonucleic acid, or DNA, the molecular key to the black box of genetic inheritance. With less fanfare, Crick went on to show how genetic information is encoded in DNA. He has also forayed into developmental biology and the origin of life.

For the past 16 years, however, ever since he left the University of Cambridge in England for the Salk Institute for Biological Studies in La Jolla, Calif., Crick has been peering into the blackest of all black boxes, the brain. He is particularly intent on laying bare the machine in the ghost of consciousness, an aspect of the brain he thinks has been unduly neglected by neurobiologists. "This field is a little bit conservative," Crick says. "It doesn't jump into something that you might consider exciting. It has to be pushed."


FRANCIS CRICK hopes to expose the machine in the ghost of consciousness. Photo: James Aronovsky.

Crick's hubris is legendary. "I have never seen Francis Crick in a modest mood," Watson quipped in the first sentence of *The Double Helix,* his classic memoir about the discovery of DNA. Crick suggests that if he is a mite bumptious at times, well, that is because he wants so badly to get to the bottom of things. "I can be patient for about 20 minutes," he says, "but that's it."

Crick embraced scientific materialism early. Born in 1916 to middle-class Congregationalist parents in Northampton, England, he renounced religion by the time he was 12 and became "an agnostic with a prejudice toward atheism." Yet his career as a biologist bloomed late. He studied physics as an undergraduate at University College in London and during World War II designed mines for the British war effort.

Deciding after the war that he was more interested in biology, he joined a laboratory in Cambridge where researchers were investigating the structure of organic molecules by diffracting X rays through them. Before long, Crick was disparaging the current X-ray diffraction methods and suggesting alternatives. His colleagues, after overcoming their annoyance ("Crick, you're rocking the boat," growled Sir Lawrence Bragg, the eminent head of the Cambridge laboratory, on overhearing one of Crick's snide critiques), realized that the brash graduate student was right and adopted his suggestions.

When he and Watson discovered DNA's structure, Crick was 37 and still a year shy of his Ph.D. He notes that contrary to what most accounts have suggested, few scientists immediately recognized the importance of the DNA finding. He and Watson did not receive the Nobel Prize (together with Maurice H. F. Wilkins, who had provided them with X-ray data) until 1962.

By that time, Crick and others had demonstrated how DNA generates amino acids, the building blocks of proteins. In 1961, in a rare venture into the laboratory (although "an experimentalist at heart," Crick has generally been content to interpret or predict the outcome of experiments of others), he showed that a "triplet" of DNA bases encodes for one amino acid. Some of his proposals have taken longer to confirm. Last October a group reported in *Science* that a broad class of proteins—found in muscle, hair and bone and recently implicated in cancer and the regulation of genes—has precisely the structure proposed by Crick in his Ph.D. thesis.

In the late 1960s Crick moved from genetics into developmental biology, which addresses the apparently miraculous transformation of a cluster of cells into a fruit fly or sperm whale or cabdriver. Thus occupied, he watched more or less from the sidelines—and with astonishment—in the 1970s as researchers began inventing powerful techniques for manipulating genes. Asked if he thinks humanity should use this knowledge to improve its genetic design, he replies, "You might almost say it's an obligation."

But first, he adds, people must purge themselves of archaic thinking patterns—especially those related to religion. "One of the most frightening things in the Western world, and this country in particular, is the number of people who believe in things that are scientifically false," he says. "If someone tells me that the earth is less than 10,000 years old, in my opinion he should see a psychiatrist."

Some scientists said the same of Crick in 1981 after the appearance of *Life Itself,* a book on the origin of life that he co-authored with Leslie E. Orgel of the Salk Institute. The book proposed that the seeds of life were sent to the earth in a spaceship launched by beings on another planet. Called directed panspermia, the theory met with derision from other scientists, and Orgel himself described it recently as "sort of a joke." But Crick insists that given the weaknesses of all theories of terrestrial genesis, directed panspermia should still be considered "a serious possibility."

Crick began indulging his long-standing interest in the brain in 1976. Much of his impact has come from his brush-clearing critiques of approaches he feels are misguided. He has warned, for example, of the "pernicious influence" of the computer as a model for the brain. Computers are designed according to logical and mathematical precepts, he observes, whereas natural selection cobbles organisms together with "gimmicks and mechanisms," with whatever works.

Crick has also cast a skeptical eye on some aspects of neural networks, computers that process and store information not serially, in one location at a time, but in parallel at many locations, as the brain is thought to do. He has been particularly disparaging about a neural network model of the brain called "neural Darwinism." Proposed by the biologist Gerald M. Edelman of the Rockefeller University, it holds that the mind is molded by competition between groups of neurons corresponding to different memories.

Crick has publicly accused Edelman of hiding not terribly original ideas behind a "smoke screen of jargon." Edelman, who like Crick possesses both a Nobel Prize and a robust ego, reportedly did not find the criticism constructive. This summer he is moving to the Scripps Institute, just down the road from the Salk. Crick dismisses the prospect of a confrontation. "I don't regard us as rivals," he says, adding, after a perfectly timed pause, "but I think he does."

The mind may spring from an assemblage of "gimmicks and mechanisms" rather than from a logical plan.

Yet Crick thinks investigating neural networks can be fruitful. In 1983 he and Graeme Mitchison of Cambridge noted that neural network computer models, when overburdened with data, sometimes cast up "pseudo-memories" that are actually composites of real ones. The researchers suggested that the brain may deliberately employ a similar mechanism during sleep to reduce its memory overload. The result: pseudo-memories called dreams.

The bulk of Crick's efforts in neurobiology has been devoted to deconstructing a phenomenon even more ineffable than dreams: consciousness. He decided early on to focus on visual awareness as a stand-in for consciousness, since the literature on vision was abundant and growing fast. But he suggests that all forms of consciousness—whether involving sensory perception, emotion or abstract thought—stem from the same fundamental mechanism, one that combines attention with short-term memory.

The phenomenon of attention involves more than the simple processing of information. To demonstrate this point, Crick pulls out a sheet of paper imprinted with a familiar black-and-white pattern: it appears as a white vase on a black background one moment and as two face-to-face human profiles the next. Although the visual input to one's brain remains constant, Crick points out, what one perceives—or attends to—keeps changing. What change in the brain corresponds to this change in attention?

Crick and Christof Koch, a neurobiologist at the California Institute of Technology, offered an answer in 1990 in *Seminars in the Neurosciences.* They noted the finding of two German groups that when cats perceive a scene, some neurons in their visual cortex fire extremely rapidly, approximately 40 times per second. These oscillating neurons, Crick and Koch suggested, correspond to aspects of a scene to which one is paying attention. If one thinks of the set of neurons stimulated by a given scene as a vast, muttering crowd, the oscillating neurons are a group that suddenly starts humming in the same key. Going back to the vase-profiles concept, first the set of neurons corresponding to the vase hums; then that set regresses to random muttering as the set corresponding to the profiles pipes up.

Crick has doubts about the theory. The German groups observed the oscillations in cats that were partially anesthetized; follow-up experiments on fully alert animals have not detected oscillations in the regions expected by Crick and Koch. On the other hand, Crick points out, he and Watson only deciphered the double helix after numerous false starts. "Exploratory research is really like working in a fog. You're just groping. Then people learn about it afterwards and think how straightforward it was."

Even Crick concedes there may be limits to how precisely scientists can know the mind. Just because the brain is a deterministic system, for example, does not mean it will ever be wholly predictable; chaos theory has shown that not to be the case for many complex systems. Consciousness may also turn out to involve processes that, like quantum physics, are paradoxical and extremely difficult to grasp. Then there are "qualia," a term used by philosophers to refer to aspects of perception, such as color, that in a certain sense are knowable only subjectively.

These tiny loopholes in Crick's relentless materialism give me some comfort as our interview comes to a close. But then, as he escorts me out of his office, we pass a table on which sits a thick stack of paper. Crick remarks that it is the first draft of his book on the brain, whose working title is *The Astonishing Hypothesis.* If I like, he says a bit too nonchalantly, I can take a look at the first paragraph. Sure, I say gratefully.

"The astonishing hypothesis," the paragraph begins, "is that you, your joys and your sorrows, your memories and ambitions, your sense of personal identity and free will, are in fact no more than the behavior of a vast assembly of nerve cells and their associated molecules. As Lewis Carroll's Alice might have phrased it, 'You're nothing but a pack of neurons.'" I look at Crick. He is grinning ear to ear. —*John Horgan*

SCIENTIFIC
AMERICAN

Indochinese Refugee Families and Academic Achievement

The children of Southeast Asian boat people excel in the American school system. A review of the factors underlying this achievement suggests that the U.S. educational crisis is more social than academic

by Nathan Caplan, Marcella H. Choy and John K. Whitmore

The scholastic success of Asian children is well recognized. Their stunning performance—particularly in the realm of science and mathematics—has prompted American educators to visit Japanese and Taiwanese schools in an effort to unearth the foundations of these achievements. Experts recommend that American schools adopt aspects of their Asian counterparts, such as a longer school year or more rigorous tasks, in order to raise the scholastic level of U.S. students.

Yet there is no need to go abroad to understand why these children do so well. The achievement of Asian-American students indicates that much may be learned about the origins of their triumph within the American school system itself. More specifically, during the late 1970s and early 1980s, devastating political and economic circumstances forced many Vietnamese, Lao and Chinese-Vietnamese families to seek a new life in the U.S. This resettlement of boat people from Indochina offered a rare opportunity to examine the academic achievement of their children.

These young refugees had lost months, even years of formal schooling while living in relocation camps. Like their parents, they suffered disruption and trauma as they escaped from Southeast Asia. Despite their hardships and with little knowledge of English, the children quickly adapted to their new schools and began to excel.

In researching the economic and scholastic accomplishments of 1,400 refugee households in the early 1980s, our group at the University of Michigan studied the forces that shaped the performance of these children. Some of the standard explanations for educational excellence—parental encouragement and dedication to learning—applied to the young students, but other theories proved inadequate.

Although some of our findings are culturally specific, others point overwhelmingly to the pivotal role of the family in the children's academic success. Because this characteristic extends beyond culture, it has implications for educators, social scientists and policymakers as well as for the refugees themselves. It is clear that the U.S. educational system can work—if the requisite familial and social supports are provided for the students outside school.

Our study encompassed many features of resettlement. We gathered survey and other data on 6,750 persons in five urban areas—Orange County, Calif., Seattle, Houston, Chicago and Boston—and obtained information about their background and home life as well as economic and demographic facts. We discovered that with regard to educational and social status, the refugees proved to be more ordinary than their predecessors who fled Vietnam in 1975 during the fall of Saigon. These newer displaced persons had had limited exposure to Western culture and knew virtually no English when they arrived. Often they came with nothing more than the clothes they wore.

From this larger group, we chose a random sample of 200 nuclear families and their 536 school-age children. Twenty-seven percent of the families had four or more children. At the time of the study, these young refugees had been in the U.S. for an average of three and a half years. We collected information on parents and their children during interviews conducted in their native tongues; we also gained access to school transcripts and other related documents.

All the children attended schools in low-income, metropolitan areas—environs not known for outstanding aca-

NATHAN CAPLAN, MARCELLA H. CHOY and JOHN K. WHITMORE collaborated on their study of Indochinese refugee resettlement while working together at the Institute for Social Research at the University of Michigan at Ann Arbor. Caplan is professor emeritus of psychology at Michigan and program director at the institute. Choy is a doctoral candidate in social psychology. Whitmore is a Southeast Asian specialist at Michigan.

VIETNAMESE BOY is one of many Southeast Asians enrolled at P.S. 122 in the Bronx, N.Y. Like many Indochinese refugee students, the eight-year-old is doing exceptionally well in mathematics.

demic records. The refugees were fairly evenly distributed throughout the school levels: grades one through 11 each contained about 8 percent of the children in the study; kindergarten and 12th grade each contained about 5 percent. We converted the students' letter grades into a numerical grade point average (GPA): an A became a four; a D became a one. After calculations, we found that the children's mean GPA was 3.05, or a B average. Twenty-seven percent had an overall GPA in the A range, 52 percent in the B range and 17 percent in the C range. Only 4 percent had a GPA below a C grade.

Even more striking than the overall GPAs were the students' math scores. Almost half of the children earned As in math; another third earned Bs. Thus, four out of five students received either As or Bs. It is not surprising that they would do better in this subject. Their minds could most easily grasp disciplines in which English was not so crucial: math, physics, chemistry and science. As expected, their grades in the liberal arts were lower: in areas where extensive language skills were required, such as English, history or social studies, the combined GPA was 2.64.

To place our local findings in a national context, we turned to standardized achievement test scores, in particular, the California Achievement Test (CAT) results. In this arena as well, we found that the performance of the newly arrived students was exceptional. Their mean overall score on the CAT was in the 54th percentile; that is, they outperformed 54 percent of those taking the test—placing them just above the national average. Interestingly, their scores tended to cluster toward the middle ranges: they showed a more restricted scope of individual differences.

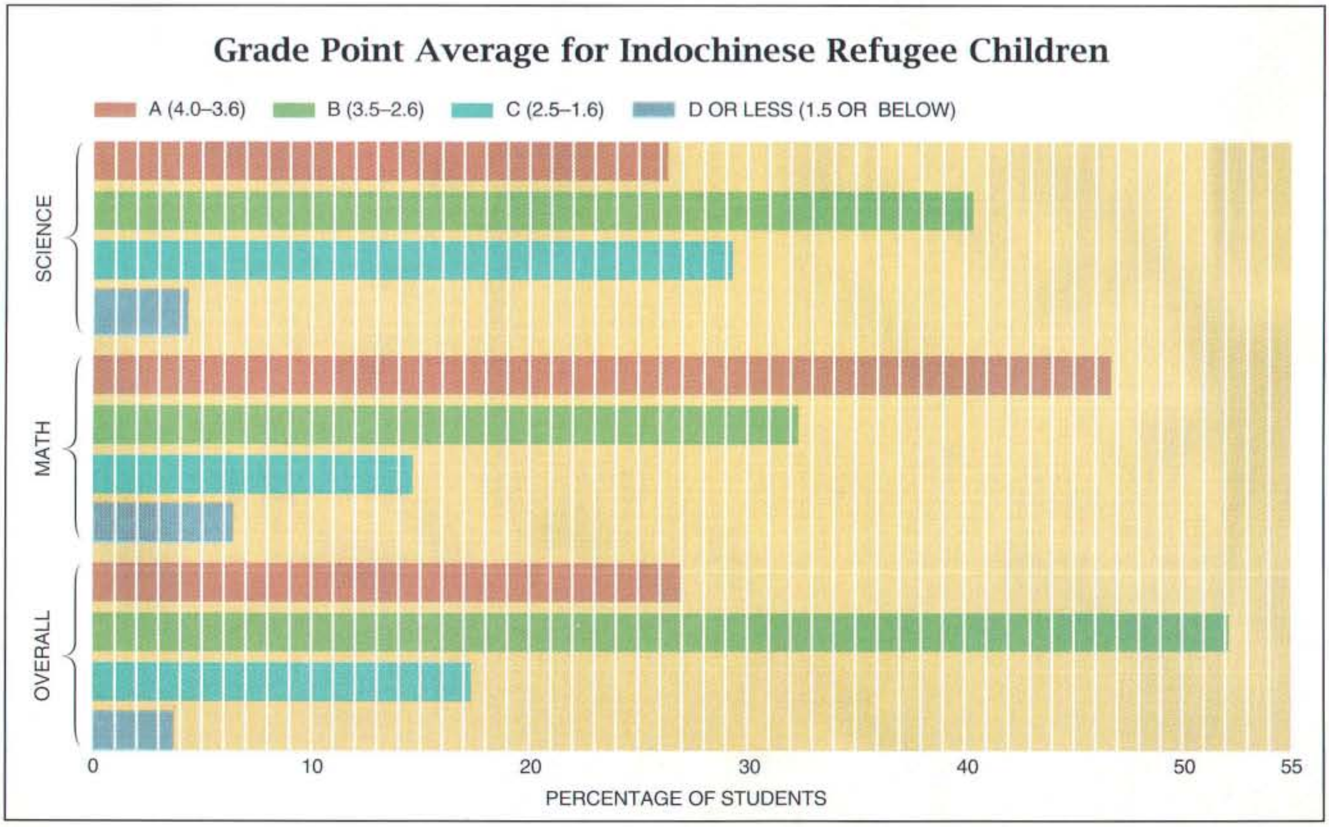
The national tests also reflected an above-average ability in math when the Indochinese children were compared with children taking the exam at equivalent levels. Half of the children studied obtained scores in the top quartile. Even more spectacularly, 27 percent of them scored in the 10th decile—better than 90 percent of the students across the country and almost three times higher than the national norm. The CAT math scores confirmed that the GPAs of these children were not products of local bias but of true mathematical competence.

Again, the lowest scores were found in the language and reading tests. In this case, the mean score was slightly below the national average. For reasons discussed earlier, this finding was expected. It remains remarkable, however, that the students' scores are so close to the national average in language skills.

The GPA and CAT scores show that the refugee children did very well, particularly in light of their background. A history marked by significant physical and emotional trauma as well as a lack of formal education would not seem to predispose them to an easy transition into U.S. schools. Yet even though they had not forgotten their difficult experiences, the children were able to focus on the present and to work toward the future. In so doing, they made striking scholastic progress. Moreover, their achievements held true for the majority, not for just a few whiz kids.

Clearly, these accomplishments are fueled by influences powerful enough to override the impact of a host of geographic and demographic factors. Using various statistical approaches, we sought to understand the forces responsible for this performance. In the process, a unique finding caught our attention, namely, a positive relation between the number of siblings and the children's GPA.

Family size has long been regarded as one of the most reliable predictors of poor achievement. Virtually all studies on the topic show an inverse relation: the greater the number of children in the family, the lower the mean GPA and other measures associated with scholastic performance. Typically, these reports document a 15 percent decline in GPA and other achievement-related scores with the addition of each child to the family. The interpretation of this finding has been subject to disagreement,


Grade Point Average for Indochinese Refugee Children

but there is no conflict about its relation to achievement.

For the Indochinese students, this apparent disadvantage was somehow neutralized or turned into an advantage. We took this finding to be an important clue in elucidating the role of the family in academic performance. We assumed that distinctive family characteristics would explain how these achievements took place so early in resettlement as well as how these children and their parents managed to overcome such adversities as poor English skills, poverty and the often disruptive environment of urban schools.

Because they were newcomers in a strange land, it was reasonable to expect that at least some of the reasons for the children's success rested on their cultural background. While not ignoring the structural forces present here in the U.S.—among them the opportunity for education and advancement—we believed that the values and traditions permeating the lives of these children in Southeast Asia would guide their lives in this country.

Knowledge of one's culture does not occur in a vacuum; it is transmitted through the family. Children often acquire a sense of their heritage as a result of deliberate and concentrated parental effort in the context of family life. This inculcation of values from one generation to another is a universal feature of the conservation of culture.

We sought to determine which values were important to the parents, how well those values had been transmitted to the children and what role values played in promoting their educational achievement. In our interviews we included 26 questions about values that were derived from a search of Asian literature and from social science research. Respondents were asked to rate the perceived importance of these values.

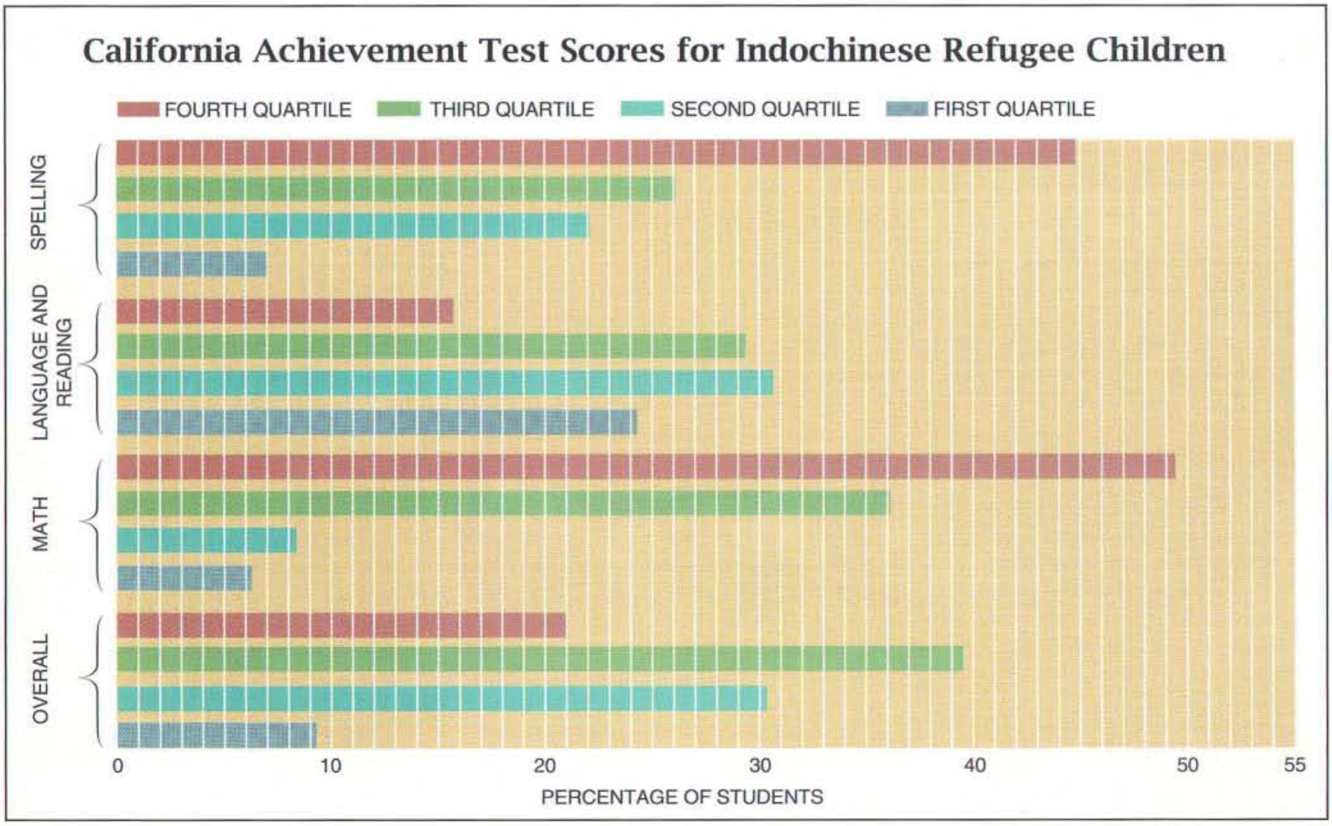
We found that parents and children rated the perceived values in a similar fashion, providing empirical testimony that these parents had served their stewardship well. For the most part, the perspectives and values embedded in the cultural heritage of the Indochinese had been carried with them to the U.S. We also determined that cultural values played an important role in the educational achievement of the children. Conserved values constituted a source of motivation and direction as the families dealt with contemporary problems set in a country vastly different from their homeland. The values formed a set of cultural givens with deep roots in the Confucian and Buddhist traditions of East and Southeast Asia.

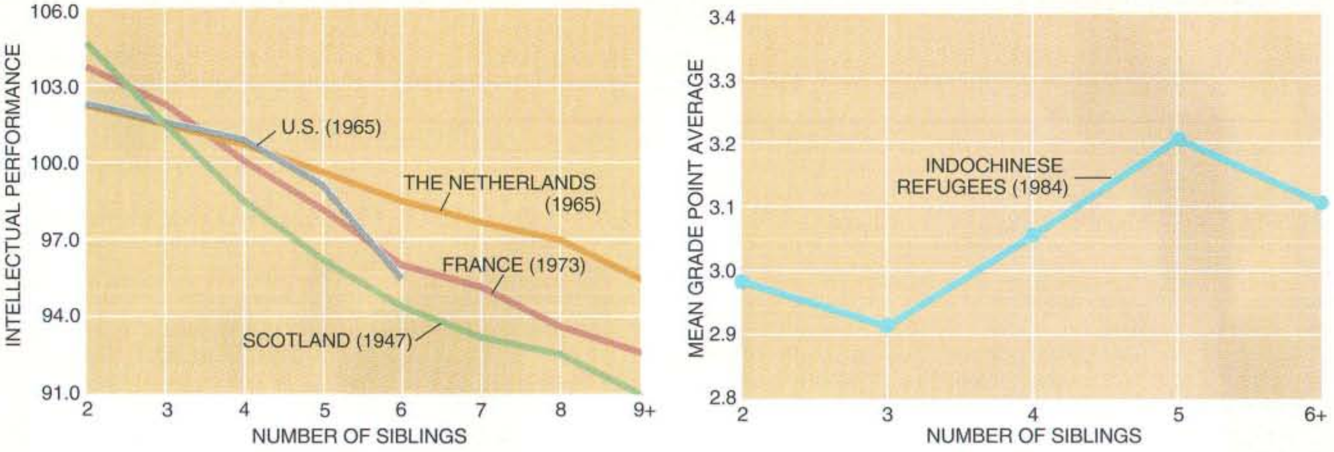
The family is the central institution in these traditions, within which and through which achievement and knowledge are accomplished. We used factor analyses and other statistical procedures to determine value groupings and their relation to achievement. These analyses showed that parents and children honor mutual, collective obligation to one another and to their relatives. They strive to attain respect, cooperation and harmony within the family.

Nowhere is the family's commitment to accomplishment and education more evident than in time spent on homework. During high school, Indochinese students spend an average of three hours and 10 minutes per day; in junior high, an average of two and a half hours; and in grade school, an average of two hours and five minutes. Research in the U.S. shows that American students study about one and a half hours per day at the junior and senior high school levels.

Among the refugee families, then, homework clearly dominates household activities during weeknights. Although the parents' lack of education and facility with English often prevents them from engaging in the content of the exercise, they set standards and goals for the evening and facilitate their children's studies by assuming responsibility for chores and other practical considerations.

After dinner, the table is cleared, and homework begins. The older children, both male and female, help their younger siblings. Indeed, they seem to





FAMILY SIZE corresponds with academic achievement. On the left, intellectual performance—as measured by IQ (*yellow, red, green*) and by standardized achievement test scores (*blue*)—falls as the number of siblings rises. In contrast, on the right, the grade point average of Indochinese students increases for the most part with the number of siblings.

learn as much from teaching as from being taught. It is reasonable to suppose that a great amount of learning goes on at these times—in terms of skills, habits, attitudes and expectations as well as the content of a subject. The younger children, in particular, are taught not only subject matter but how to learn. Such sibling involvement demonstrates how a large family can encourage and enhance academic success. The familial setting appears to make the children feel at home in school and, consequently, perform well there.

Parental engagement included reading regularly to young children—an activity routinely correlated to academic performance. Almost one half (45 percent) of the parents reported reading aloud. In those families, the children's mean GPA was 3.14 as opposed to 2.97 in households where the parents did not read aloud. (This difference, and all others to follow in which GPAs are compared, is statistically reliable.) It is important to note that the effects of being read to held up statistically whether the children were read to in English or in their native language.

This finding suggests that parental English literacy skills may not play a vital role in determining school performance. Rather, other aspects of the experience—emotional ties between parent and child, cultural validation and wisdom shared in stories read in the child's native language, or value placed on reading and learning—extend to schoolwork. Reading at home obscures the boundary between home and school. In this context, learning is perceived as normal, valuable and fun.

Egalitarianism and role sharing were also found to be associated with high academic performance. In fact, relative equality between the sexes was one of the strongest predictors of GPA. In those homes where the respondents disagreed that a "wife should always do as her husband wishes," the children earned average GPAs of 3.16. But children from homes whose parents agreed with the statement had an average GPA of 2.64. In households where the husband helped with the dishes and laundry, the mean GPA was 3.21; when husbands did not participate in the chores, the mean GPA was 2.79.

This sense of equality was not confined to the parents—it extended to the children, especially in terms of sex-role expectations and school performance. GPAs were higher in households where parents expected both boys and girls to help with chores. Families rejecting the idea that a college education is more important for boys than for girls had children whose average GPA was 3.14; children from families exhibiting a pro-male bias had a mean GPA of 2.83.

Beyond the support and guidance provided by the family, culturally based attributions proved to be important to refugees in their view of scholastic motivation. The "love of learning" category was rated most often by both parents and students as the factor accounting for their academic success. There appeared to be two parts to this sentiment. First, the children experienced intrinsic gratification when they correctly worked a problem through to completion. The pleasure of intellectual growth, based on new knowledge and ideas and combined with increased competence and mastery, was considered highly satisfying. Second, refugee children felt a sense of accomplishment on seeing their younger siblings learn from their own efforts at teaching. Both learning and imparting knowledge were perceived as pleasurable experiences rather than as drudgery.

The gratification accompanying accomplishment was, in turn, founded on a sense of the importance of effort as opposed to ability. The refugees did not trust fate or luck as the determinant of educational outcome; they believed in their potential to master the factors that could influence their destiny. And their culture encompasses a practical approach to accomplishment: setting realistic goals. Without the setting of priorities and standards for work, goals would remain elusive. But anyone endorsing the values of working in a disciplined manner and taking a long-term view could establish priorities and pursue them.

Belief in one's own ability to effect change or attain goals has long been held to be a critical component of achievement and motivation—and our findings support this conclusion. Parents were asked a series of questions relating to their perceived ability to control external events influencing their lives. Those who had a clear sense of personal efficacy had children who attained higher GPAs.

We had some difficulty, however, interpreting the perception of efficacy as an idea generated solely by the individual. Despite a vast social science literature asserting the contrary, we believe that these refugees' sense of control over their lives could be traced to family identity. It seemed to us that the sense of familial efficacy proved critical, as opposed to the more Western concept of personal efficacy.

Other cultural values show us that the refugee family is firmly linked not only to its past and traditions but to the realities of the present and to future possibilities. This aptitude for integrating the past, present and future appears to have imparted a sense of continuity and direction to the lives of these people.

Education was central to this integration and to reestablishment in the U.S. It was and still is the main avenue for refugees in American society to succeed and survive. In contrast, education in Indochina was a restricted privilege. The future of the refugee children, and of their families, is thus inextricably linked to schools and to their own children's performances within them. The emphasis on education as the key to social acceptance and economic success helps us understand why academic achievement is reinforced by such strong parental commitment.

Outside school, the same sense of drive and achievement can be seen in the parents. Having a job and being able to provide for the family is integral to family pride. Shame is felt by Asian families on welfare. Reflecting the same determination and energy that their children manifest in school, Indochinese parents have found employment and climbed out of economic dependency and poverty with dispatch.

Two of the 26 values included as a measure of cultural adaptation entailed integration and the acceptance of certain American ways of life: the importance of "seeking fun and excitement" and of "material possessions." These ideas are of particular concern because they address the future of refugee families and mark the potential power and consequence of American life on the refugees and subsequent generations. Not surprisingly, when our subjects were asked to indicate which values best characterized their nonrefugee neighbors, these two items were most frequently cited.

More interesting, however, was our finding that these same two values were correlated with a lower GPA. We found that parents who attributed greater importance to fun and excitement had children who achieved lower GPAs: 2.90 as opposed to 3.14. The results for material possessions were similar: GPAs were 2.66 versus 3.19.

It is not clear why these negative associations exist. Do they reflect less strict parents or families who have integrated so quickly that cultural stability has been lost? We believe it is the latter explanation. Refugees who held that "the past is as important as the future" had children whose GPAs averaged 3.14. Children of those who did not rate the preservation of the past as highly had an average GPA of 2.66. This item was one of the most powerful independent predictors of academic performance.

Our findings run contrary to expectations. Rather than adopting American ways and assimilating into the melting pot, the most successful Indochinese families appear to retain their own traditions and values. By this statement we are in no way devaluing the American system. The openness and opportunity it offers have enabled the Indochinese to succeed in the U.S. even while maintaining their own cultural traditions.

Although different in origins, both traditional Indochinese and middle-class American values emphasize education, achievement, hard work, autonomy, perseverance and pride. The difference between the two value systems is one of orientation to achievement. American mores encourage independence and individual achievement, whereas Indochinese values foster interdependence and a family-based orientation to achievement. And in view of the position of these refugees in society during the early phase of resettlement in this country, this approach appears to have worked well as the best long-term investment. It appears to be the reason why these children are highly responsive to American schools.

The lack of emphasis on fun and excitement also does not indicate misery on the part of these refugee children. Despite evidence that the suicide rate is growing among some Asian-American children, we found that those in our sample were well adjusted. Our interviews revealed no damaging manipulation of their lives by their parents; moreover, their love of learning sustained their academic pursuits.

The Indochinese values that encourage academic rigor and excellence are not culturally unique: earlier studies of other groups have found similar re-

HOMEWORK is a joint effort in many Southeast Asian refugee families. After dinner in such households, the table is cleared, and the parents encourage their children to study. The older siblings often help teach the younger ones.

INDOCHINESE STUDENTS often adapt quickly to U.S. schools because studying and learning are an integral part of home life: there is little schism between the two worlds. Like this Vietnamese girl, such students feel comfortable in the classroom.

sults. The children of Jewish immigrants from Eastern Europe, for example, excelled in the U.S. school system. In 1961 Judith R. Kramer of Brooklyn College and Seymour Leventman of the University of Pennsylvania reported that nearly 90 percent of the third generation attended college, despite the fact that the first generation had little or no education when they arrived in the U.S. Their emphasis on family and culture was held to be instrumental in this success.

In 1948 William Caudill and George DeVos of the University of California at Berkeley found that Japanese students overcame prejudice in U.S. schools immediately after World War II and thrived academically. Their success was attributed to cultural values and to parental involvement. More recently, a study by Reginald Clark of the Claremont Graduate School documented the outstanding achievement of low-income African-American students in Chicago whose parents supported the school and teachers and structured their children's learning environment at home.

These findings, as well as our own, have significance for the current national debate on education. It is clear that the American school system—despite widespread criticism—has retained its capacity to teach, as it has shown with these refugees. We believe that the view of our schools as failing to educate stems from the unrealistic demand that the educational system deal with urgent social service needs. Citizens and politicians expect teachers and schools to keep children off the streets and away from drugs, deal with teenage pregnancy, prevent violence in the schools, promote safe sex and perform myriad other tasks and responsibilities in addition to teaching traditional academic subjects.

As the social needs of our students have moved into the classroom, they have consumed the scarce resources allocated to education and have compromised the schools' academic function. The primary role of teachers has become that of parent by proxy; they are expected to transform the attitude and behavior of children, many of whom come to school ill prepared to learn.

If we are to deal effectively with the crisis in American education, we must start with an accurate definition of the problem. We must separate teaching and its academic purpose from in-school social services. Only then can we assess the true ability of schools to accomplish these two, sometimes opposing, functions—or we can identify and delegate these nonacademic concerns to other institutions.

Throughout this article we have examined the role of the family in the academic performance of Indochinese refugees. We firmly believe that for American schools to succeed, parents and families must become more committed to the education of their children. They must instill a respect for education and create within the home an environment conducive to learning. They must also participate in the process so that their children feel comfortable learning and go to school willing and prepared to study.

Yet we cannot expect the family to provide such support alone. Schools must reach out to families and engage them meaningfully in the education of their children. This involvement must go beyond annual teacher-parent meetings and must include, among other things, the identification of cultural elements that promote achievement.

Similarly, we cannot adopt the complete perspective of an Indochinese or any other culture. It would be ludicrous to impose cultural beliefs and practices on American children, especially on those whose progress in this country has been fraught with blocked access.

We can, however, work to ensure that families believe in the value of an education and, like the refugees, have rational expectations of future rewards for their efforts. Moreover, we can integrate components of the refugees' experience regarding the family's role in education. It is possible to identify culturally compatible values, behaviors and strategies for success that might enhance scholastic achievement. It is in this regard that the example of the Indochinese refugees—as well as the Japanese and Jewish immigrants before them—can shape our priorities and our policies.

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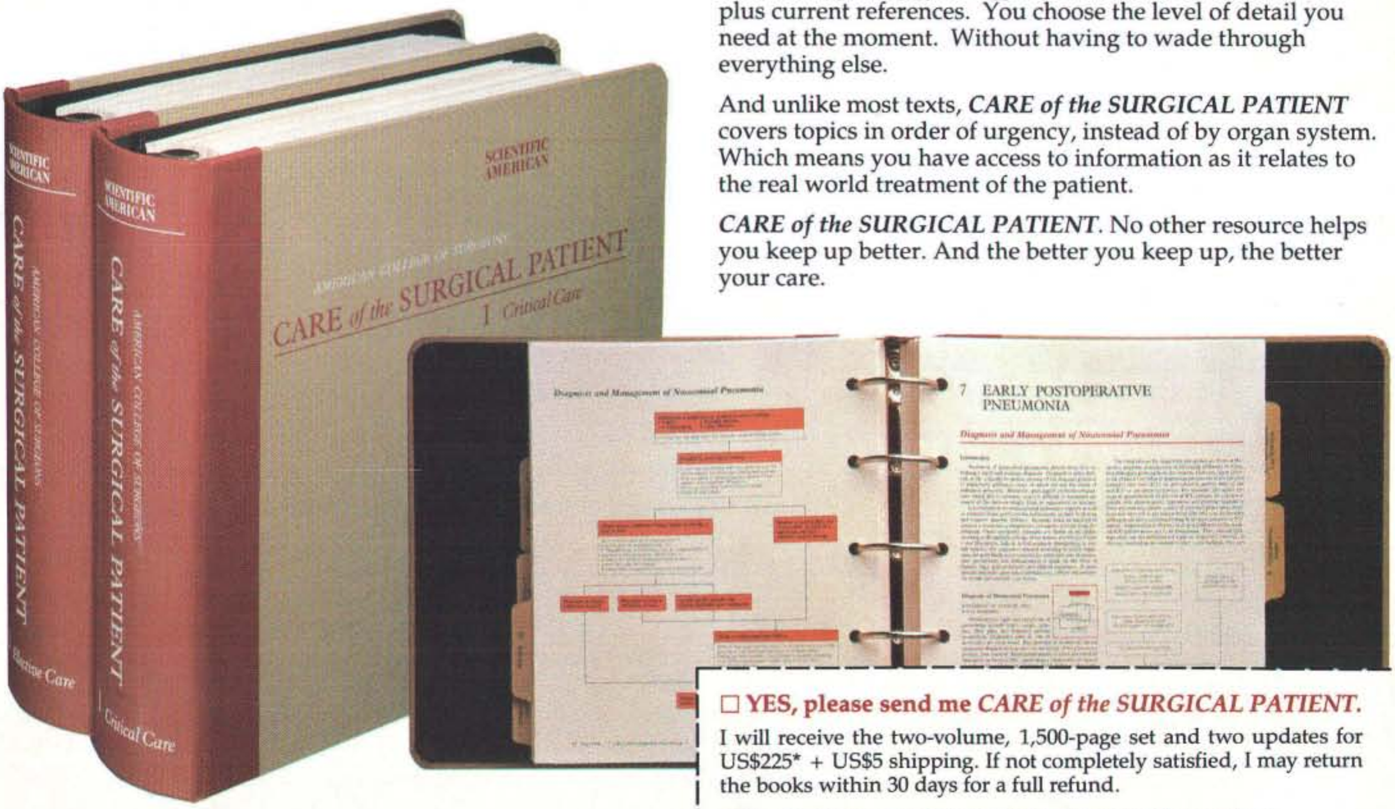
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Mud Volcanoes of the Marianas

Mantle rock, transformed into serpentine mud by fluids distilled from the subducting Pacific plate, oozes up along faults near the Mariana Trench to form mountains on the seafloor

by Patricia Fryer

Almost 4,000 meters below the surface of the Pacific Ocean, Dudley B. Foster switched on the *Alvin* submersible's external lights. Janet A. Haggerty and I peered through our four-inch portholes, looking for the first glimpse of the seafloor. A couple of minutes later we settled on a lightly sedimented incline amid a cluster of small, white-streaked, green boulders. For the next five hours, cold and bent in fetal positions in the cramped interior of the *Alvin,* we completely forgot physical discomforts as we explored a mountain of green mud 80 kilometers west of the Mariana Trench.

The unusual composition of this seamount, one of dozens of large seamounts scattered over a 100- by 1,000-kilometer zone just west of the world's deepest undersea trench, suggested new answers to a number of open questions in marine geology. Chief among them was the fate of water and other fluids released from rocks during subduction.

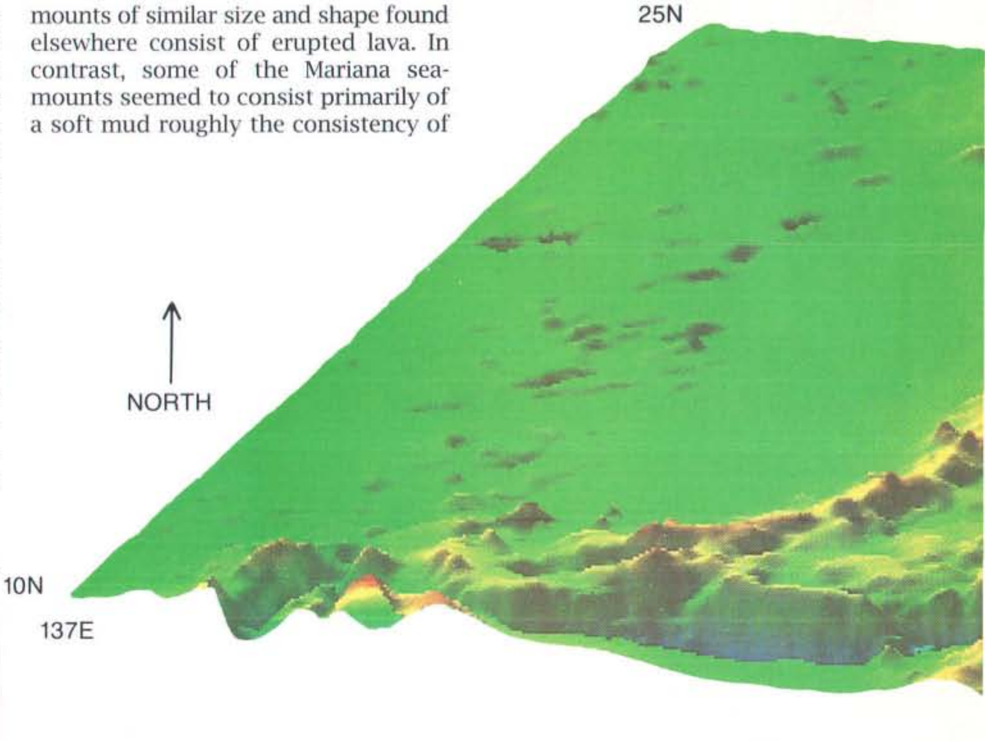
Subduction takes place when the plates of the earth's lithosphere collide and one is pushed down into the mantle. Heat and pressure act to dehydrate rocks of the descending plate, but it has long been unclear to geologists just where all the fluid goes. I and some of my colleagues had formed the tentative outlines of a theory suggesting that fluids expelled from a subducting plate reacted with mantle rock and transformed parts of the mantle into low-density minerals that could rise slowly through the subduction zone to the seafloor. Nevertheless, I was not at all sure what awaited us in the Marianas.

Before boarding the *Alvin* in 1987, we had spent more than a decade surveying, sampling and obtaining sonar images of the Mariana seamounts. The pilot Foster, from Woods Hole Oceanographic Institution, Haggerty, from the University of Tulsa, and I had come down for a firsthand look at an edifice that would appear to defy the rules of both plate tectonics and geochemistry.

These enigmatic seamounts of the Mariana forearc—the region where the Pacific lithospheric plate is subducted to the northwest under the Philippine Sea plate—are gently sloping structures one to two kilometers high and 15 to 30 kilometers across at the base. Seamounts of similar size and shape found elsewhere consist of erupted lava. In contrast, some of the Mariana seamounts seemed to consist primarily of a soft mud roughly the consistency of cream cheese. And although structures of similar consistency do exist, such so-called mud volcanoes—mounds of remobilized sediments formed in association with hydrocarbon seeps—are only a few hundred meters high and contain an entirely different set of minerals from those we were finding.

The first inklings that the Mariana seamounts were unusual came in the late 1970s. Geophysicists had expected that any seamounts in the forearc would be volcanic. The Mariana islands, after all, formed from magma generated above parts of the Pacific plate that had descended to a depth of about 80 to 150 kilometers.

PATRICIA FRYER has spent most of her career investigating the geology of the Mariana region. She is an associate planetary scientist in the School of Ocean and Earth Science and Technology at the University of Hawaii at Manoa, where she received her doctorate in geology and geophysics. Fryer reports that her spare moments are devoted to family, music and sewing for her daughter's dolls.



MARIANA FOREARC to the west of the Mariana Trench (due south of the Philippines) lies above the subducting Pacific plate. Metamorphosed mantle rocks rise through faults in the forearc to form undersea mountains. The author and her colleagues discovered these unusual seamounts and developed a theory of their origin.

The marine geophysical data that we collected, however, were inconsistent with this interpretation. For example, volcanic seamounts generally display a strong magnetic signature because the earth's magnetic field aligns magnetic minerals crystallizing from the lava. This alignment makes the seamount act rather like a large magnet. Volcanic seamounts in the ocean basins also have a positive gravity signature that reflects their anomalously large mass as compared with the regional gravity signature of the surrounding oceanic plate. Some seamounts of the Mariana forearc lacked both these characteristics.

Since that time, geologists interested in the region have interleaved theoretical modeling and fieldwork to determine what makes up these seamounts and how they were formed. Our tentative understanding of the mechanics and fluid chemistry of subduction zones has told us what data to collect, and analysis of the data has immeasurably enriched that understanding.

Donald M. Hussong, then at the University of Hawaii (now president of Seafloor Surveys International), and I suspected that the extraordinary seamounts might be diapirs, masses of relatively low density rock that rise by gravitational instability through the overlying strata. (The salt diapirs of the Gulf of Mexico are perhaps the best-known example.) In the case of the Mariana forearc, we thought the diapirs were most likely to be composed of mantle rock that had been altered by interaction with fluids distilled from the underlying Pacific lithospheric plate.

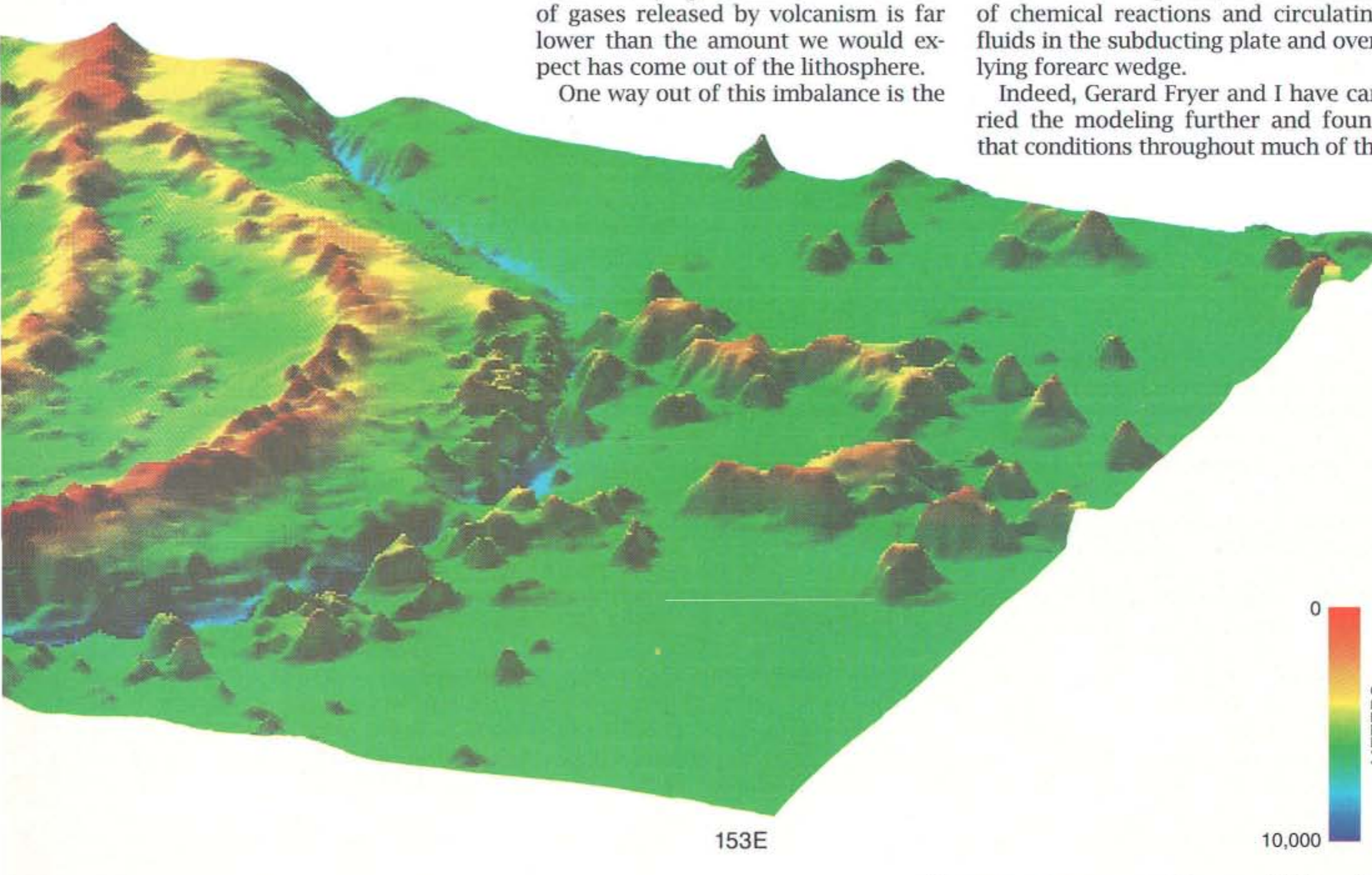
As the Pacific plate descends, the sediments and rocks of which it is composed lose water by various physical and chemical processes. On the way from the seafloor to 15 kilometers down, the increasing pressure of the overlying rock squeezes pore fluids out of the sediments and drives fluids out of fractures and other openings in the rocks. These fluids escape to the floor of the Mariana Trench and percolate back up along the boundary between the two converging plates, or else they seep into the forearc rock overlying the boundary. Next the plate undergoes a series of chemical reactions that release water and different soluble compounds in the rocks. This dehydration is suspected to continue to occur to depths of well over 200 kilometers beneath the arc system.

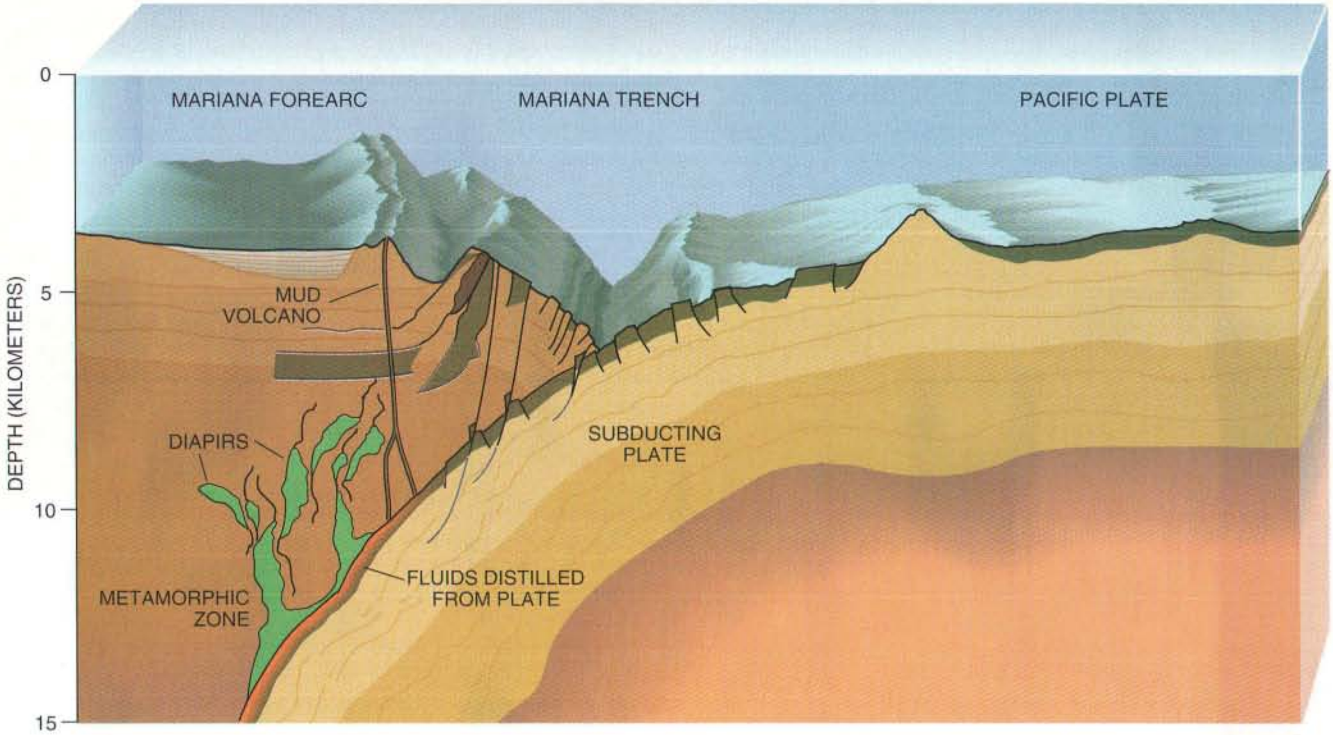
Where do these fluids go? Investigators of the geochemical balance of subducting plates have been troubled by this question for decades. Oceanic lithosphere has been vanishing into the Mariana subduction zone for at least 45 million years, and enormous quantities of fluids have probably been distilled from it. Yet the volume of fluids coming out of the overlying Mariana arc in the form of gases released by volcanism is far lower than the amount we would expect has come out of the lithosphere.

One way out of this imbalance is the concept of a "metamorphic sponge." The fluids released from the lithosphere trigger metamorphism of the overlying mantle rocks, essentially reversing the reactions that drove water out of the subducting crust. Such a convenient answer, however, requires a special set of conditions: both the mineralogy of the mantle rocks and the ambient temperature and pressure must be such that metamorphism can take place.

In typical 150-million-year-old oceanic lithosphere, the increase in temperature with depth would lead to a temperature of 500 degrees Celsius at a depth of about 30 kilometers. But theoretical models of the thermal structure of the Mariana region by Gerard Fryer of the University of Hawaii imply that the top of the Pacific plate 100 kilometers west of the Mariana Trench axis and about 30 kilometers under the forearc is at a temperature of only about 100 degrees C. The Pacific plate lowers the temperature of the deeper crust and mantle through which it descends during subduction. If the rate of cooling falls within a certain range, the subduction system will maintain anomalously cool temperatures at depth. This depends on the rate and angle of subduction, the age of the crust (and so the degree to which it had already cooled), the rate of convection in the mantle overlying the subducting plate, the amount of friction between plates, and the effects of chemical reactions and circulating fluids in the subducting plate and overlying forearc wedge.

Indeed, Gerard Fryer and I have carried the modeling further and found that conditions throughout much of the





METAMORPHIC SPONGE model explains the fate of fluids expelled from subducting oceanic plates. The author asserts that rocks overlying the plate absorb the distilled fluids by means of reactions that form low-density minerals such as serpentine. The serpentine rises along fault lines toward the seafloor in diapiric blocks or as cold volcanic mud.

forearc region favor the metamorphism of mantle rocks to minerals of the blueschist and greenschist facies (a family of related minerals), which form at low to moderate temperature and pressure. These models, then, give credence to the concept of the metamorphic sponge.

If such a sponge exists to soak up fluids from the descending crust, what does it consist of? The principal type of rock in the forearc mantle is peridotite, a rock rich in the mineral olivine. Under the temperature and pressure conditions prevalent in the Mariana forearc, olivine reacts with water to form serpentine, an asbestos mineral.

This transformation expands the volume of the peridotite, and so the metamorphosed peridotite becomes less dense than the surrounding mantle. Blobs of serpentine can then rise as diapirs—an observation that links theory and modeling directly to what we found on the seafloor.

During several marine geologic cruises in the late 1970s and early 1980s, James W. Hawkins of Scripps Institution of Oceanography, his student Sherman Bloomer, now at Boston University, and I dredged samples from more than 40 sites on the seamounts of the Mariana forearc. Bloomer noted that the trace element composition of the freshest peridotite samples was similar to that of island arc magmas. He surmised that the growth of the Mariana volcanic island arc above the subduction zone probably produced most of the forearc region.

He then formed a hypothesis about the nature of the seamounts: subduction at the Mariana Trench (beginning about 45 million years ago) would have caused tectonic erosion that ate away perhaps 50 to 60 kilometers of forearc. This erosion in turn would have led to tensional faulting of the forearc (an assumption later confirmed by seismic reflection studies). Serpentine deforms easily if subjected to stress, leading Bloomer to reason that the seamounts were diapirs of serpentine that had risen along the faults.

Analysis of serpentine samples from several seamounts in the Mariana forearc provides circumstantial support for both the concept of the widespread metamorphism of the forearc wedge and the possibility of diapirism. The composition of the rocks and the kind of metamorphism they have undergone vary only slightly, suggesting that the whole of the forearc mantle had indeed achieved early in its history a vast region in which conditions were favorable for low to moderate temperature and pressure metamorphism.

One of the dredge samples, however, made it clear that the picture was more complex than the simple rise of serpentine diapirs along fault lines. A haul in 1981 from a seamount in the southernmost part of the forearc brought up some white carbonate rock with very unusual texture, and I asked my colleague Janet Haggerty to examine the samples. She discovered that the carbonate contained aragonite, a mineral unstable at the depths from which the sample was retrieved. At those depths and water temperatures, the aragonite should have dissolved within a year.

Haggerty also noticed that the sample contained numerous small holes surrounded by crystals of aragonite and calcite. She surmised that fluids percolating through vents had caused the crystals to form. The compositions and the oxygen and carbon isotopic ratios of the samples indicated that the fluid with which they had been in equilibrium was not seawater. Haggerty thought she was looking at chimney fragments.

These would not have been black smokers, the kind of chimneys made famous by exploration of the hydrothermal systems of mid-ocean ridge crests. Rather than being formed from exhalations of hot seawater circulating near the magma chambers of the ridge crests, these carbonate chimneys probably arose by gentle seeping of relatively cool fluids through fractures in the Mariana forearc. We wondered whether those fluids could have derived from the subducted Pacific plate. If active venting of subduction-related fluids were a common phenomenon on the seafloor, associated with fractures or serpentine diapirism, it would further help balance the fluid budget of subduction zones.

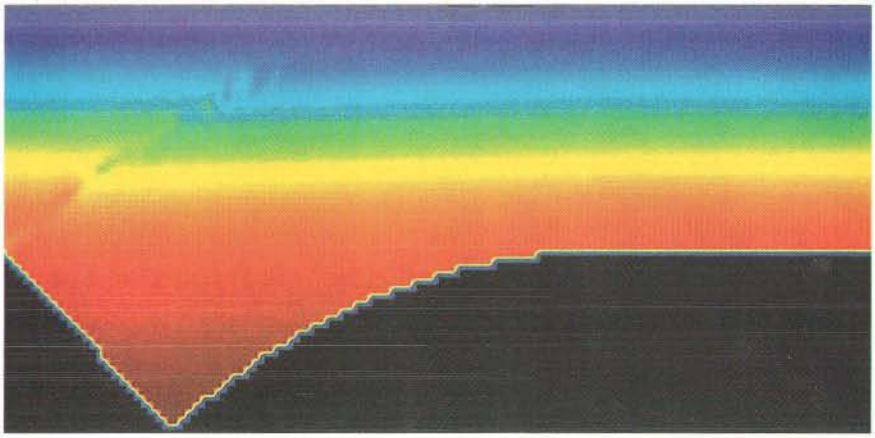
At this point, only a few details were known about the relation between the seamounts and the surrounding forearc seafloor or about the characteristics of the individual seamounts. Questions about the origin, structure and composition of these seamounts could be addressed only by high-resolution seafloor mapping.

In 1983, two years after the cruise in which we retrieved the unusual carbonate sample, we surveyed the outer Mariana forearc by sonar and found two serpentine seamounts. One appeared to be a block that had been broken by faulting on its eastern side, resulting in a crescent-shaped structure. The other was roughly conical, with a profile similar to that of basaltic shield volcanoes such as those of Hawaii or Iceland.

The sonar images of Conical Seamount, as we came to call the second edifice, show several concentric ridges on the lower flanks of the southeastern side, reminiscent of the pressure ridges one might expect from an edifice deforming under its own weight. By far the most spectacular features, however, are the long, dark, sinuous patches that cover most of its flanks. Dark areas on these sonar images indicate regions—usually rough surfaces—that reflect sound strongly back to the receiver. Such rough areas are typical of lava flows. But samples dredged from the flow areas on Conical Seamount contained only serpentinized peridotite, a few small manganese nodules and some serpentine sediments.

The crescent-shaped seamount (which we nicknamed Pacman) lacked these sinuous features. Instead there was only a single, large oval flow. It partially filled the down-faulted chasm (graben) on the east side of the seamount, and dredging there yielded serpentinized peridotite and some serpentine sediments. Dredges from the south arm of the fault graben retrieved serpentinized peridotite with virtually the same composition as the rocks of the flow.

100,000 YEARS AFTER SUBDUCTION



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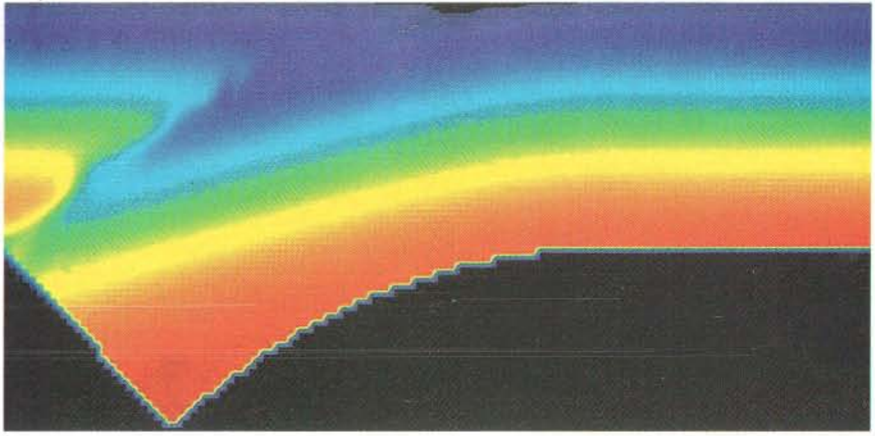

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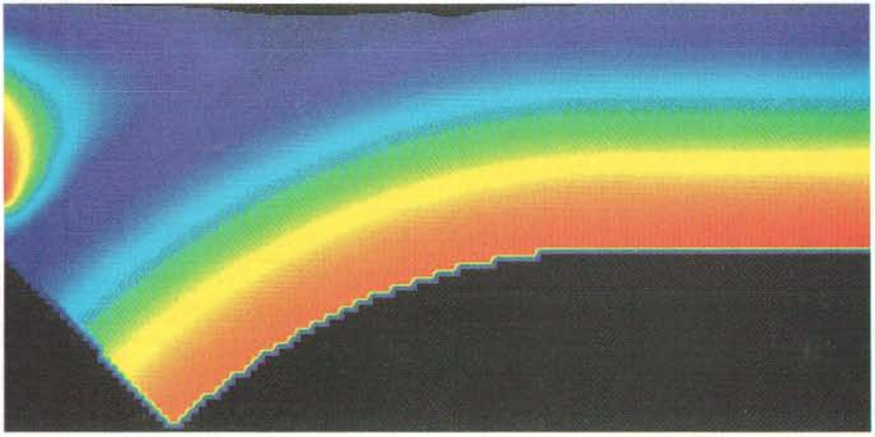
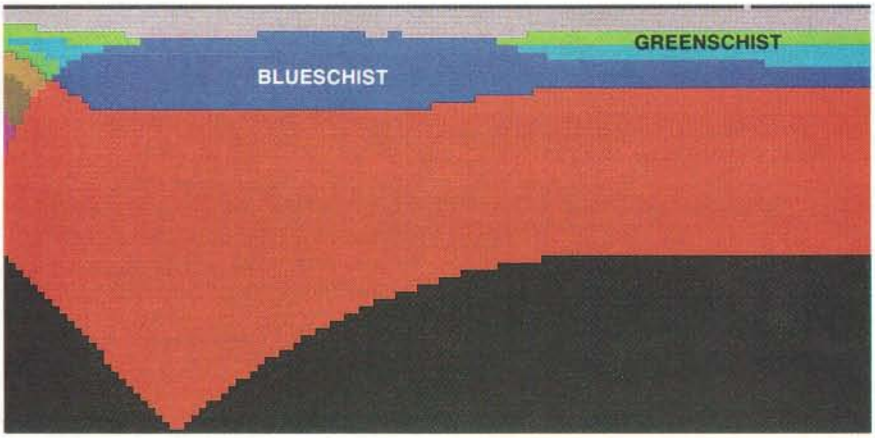
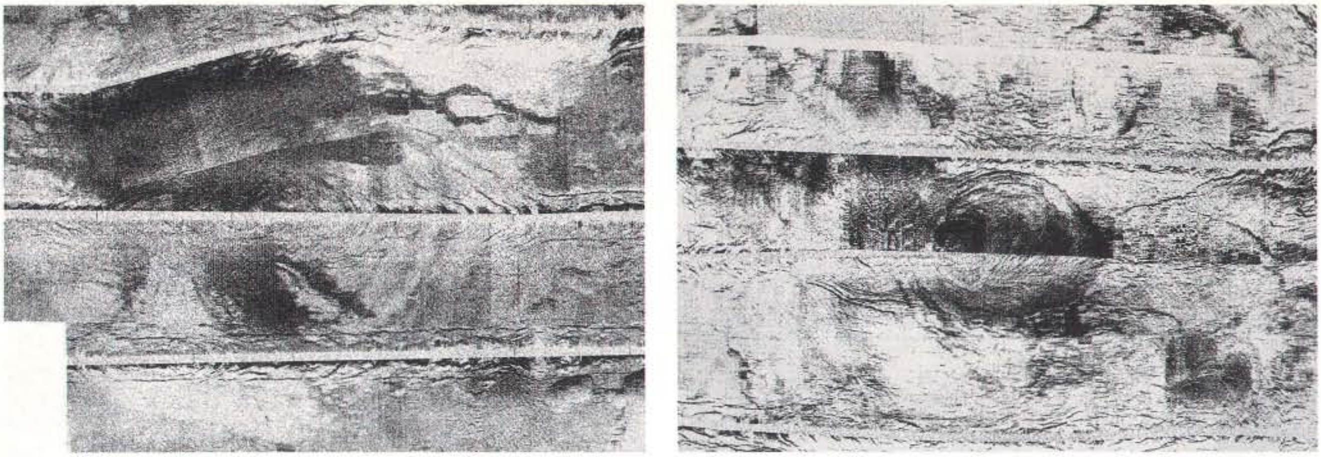
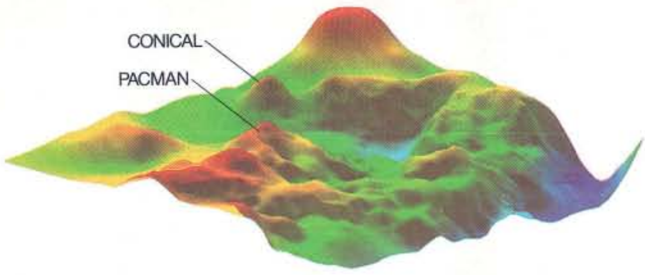




SUBDUCTING PACIFIC PLATE cools the region of mantle into which it penetrates (*top three panels*). Temperature and pressure conditions in the Mariana region favor blueschist and greenschist metamorphism (named for the families of rock to which they give rise).





SEAMOUNTS studied by sidescan sonar and depth soundings show evidence of features usually interpreted as lava flows. In this case, however, the flows consist not of lava but of serpentine, an asbestos mineral formed when peridotite reacts with water at moderate pressure and temperature.

Once the geophysical surveys, the seafloor mapping and the reconnaissance sampling had been completed, the stage was set for detailed fieldwork on the seafloor. Whereas the geologist working on land usually explores a field area on foot, the marine geologist travels by submersible.

That was what put Foster, Haggerty and me in the confines of a cold, damp metal sphere. In the summer of 1987 I led an *Alvin* diving cruise to the Mariana forearc to explore the Conical and Pacman seamounts. The first dives on Conical Seamount showed that the light regions on the sonar images corresponded to flat, lightly sedimented seafloor and the dark, sinuous features to rough, contorted fields of green mud and dark boulders. These are the flows. They are composed of unconsolidated serpentine mud and boulders of variously serpentinized peridotite.

On the fourth dive, after about three hours of exploring the southwest flank of Conical Seamount, the *Alvin* approached the relatively flat notch in the southwest side of the summit. The scientific observer on the dive, Debra Stakes of the University of South Carolina, reported back to us by radio as a field of white, ghostly chimneys came into view near the center of the notch. She and the pilots spent the remainder of the dive exploring, photographing and sampling what we came to call "the graveyard," an area about 200 meters across containing hundreds of these carbonate chimneys. The samples she brought back were nearly identical to the carbonate samples dredged in 1981 from the seamount in the southern Mariana forearc.

We devoted several of the remaining dives to exploring the chimney field. The carbonate chimneys are thin and generally less than two meters high. Their surfaces are embayed, giving them a corroded appearance. We observed carbonate encrustations filling many of the numerous small cracks in the seafloor and a carbonate precipitate at the base of the boulders. At no time during the sampling of these chimney structures, however, did any of us see emanations of fluids.

At the periphery of the field are several other chimney structures. These are thicker and taller, up to a few meters high. They occasionally coalesce to form ramparts and are usually encrusted with a black manganese deposit. One structure, however, had a light-colored top, with a smooth but irregular surface mottled by small patches of pale yellow-green bacterial mats. We suspected it was an actively forming chimney. After we collected samples from the surface, we scraped the top of the chimney to detect—and sample if possible—any venting fluids that might be associated with its formation.

The *Alvin* pilots are used to dealing with hydrothermal chimneys that vent dramatically when their tops are knocked off. What happened when we scraped this chimney was so subtle that the pilot was at first reluctant to acknowledge any activity. After some minutes, however, it became obvious that indeed small jets of fluid were escaping from the surface of the chimney: more seeping than venting.

We measured the temperature of the interior of one of the orifices in the chimney and discovered that the temperature in the orifice was slightly lower (by 0.03 degree C) than the ambient seawater temperature at that depth. Crystallization of minerals from solution is an endothermic reaction (requiring energy in order to proceed), and it is possible that the precipitation of the mineral that makes up the chimney could account for this slight lowering of the fluid temperature.

La Verne D. Kulm of Oregon State University and his colleagues had already found low-temperature seeps and carbonate chimneys in the Oregon forearc in 1986, but the Conical Seamount chimney was very different. The chimneys of the Oregon subduction zone are associated not with serpentine diapirs but with fluids squeezed out of a wedge of sediment accreted to the forearc from the oceanic plate.

Furthermore, Haggerty later discovered that the chimney we were dealing with was not composed of carbonate. It contains a previously unknown mineral, a magnesium silicate analogous to the aluminum silicate clay allothane. She analyzed the oxygen and carbon isotopic content of the carbonate samples and determined that the chimneys, like those of the southern Mariana forearc seamount dredged in 1981, formed in equilibrium with fluids other than seawater.

Samples of the seeping fluids from the silicate chimney have unusually high pH (9.28 versus 7.72 for ambient seawater) and high alkalinity. These vent waters are 500 times as rich in methane as seawater, are six times as rich in silica, are about 6 percent richer in sulfate and contain hydrogen sulfide that is not present in the ambient seawater at all. Seawater probably mixed with the slow-seeping fluids during sampling, and so these numbers must be taken as minimum estimates.

No chimney structures were observed on Pacman Seamount, and the fault scarps exposing the interior of the seamount showed no flows, only massive serpentinized peridotite. These investigations led us to believe that the Pacman and Conical seamounts represent two different paths by which metamorphosed mantle rocks reach the seafloor. Pacman Seamount is probably an uplifted block of serpentinized peridotite, similar to much of the forearc mantle. Possibly it is a large, essentially intact, diapir of serpentine. The "flow" on its eastern flank is probably a slump deposit of serpentine initiated by the faulting that formed the graben there. We suspect that Conical Seamount is essentially a mud volcano with a central conduit through which erupt cold flows of serpentine mud, charged with fluids derived from depth.

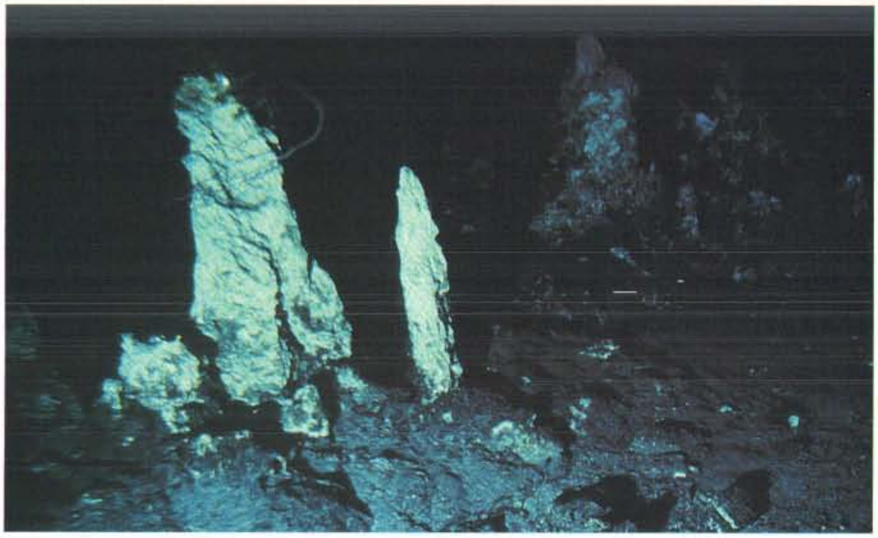
Although it appeared that the rocks exposed at the surface of the seamounts had been brought up from depth through the forearc, no one knew what types of rock underlie the seamounts. We were anxious to sample as much of the vicinity as possible. By day, we dove with the *Alvin* submersible; during the night, we dredged material from a scarp in the downfaulted graben east of the seamounts.

Most of the rock types previously dredged from the Mariana forearc have trace element compositions that indicate (as do the peridotites) derivation from an island-arc magma source. Such compositions are consistent with the Mariana forearc having formed by tectonic erosion rather than by the piecemeal addition of slivers of the oceanic plate to the forearc. The samples from this 2,000-meter-deep fault scarp suggest a different scenario.

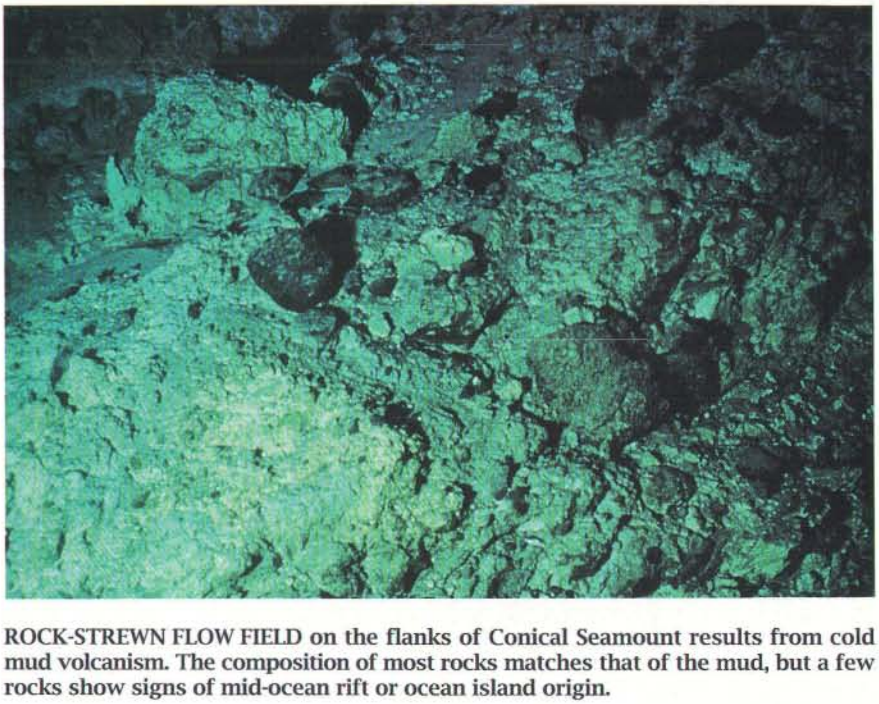
Lynn E. Johnson, then a graduate student at the University of Hawaii, analyzed the lavas from the dredged samples and found that some matched not the signatures of arc magmas but those of mid-ocean ridge basalt and of basalts typical of oceanic islands. Chert, a silica-rich sedimentary rock composed of radiolaria (one-celled organisms that excrete silica), also came up in a dredge from the same escarpment. The ages of the radiolaria indicate that the chert samples are more than 95 million years old, 50 million years older than the subduction zone itself.

The discovery of mid-ocean ridge basalt, ocean island basalt and chert in these samples required a reevaluation of the existing models of the evolution of the Mariana forearc region. Perhaps oceanic crust accreted to the forearc and was preserved there (albeit clearly intimately associated with arc-derived lavas). But that would make unlikely the tectonic erosion of as much as 60 kilometers of forearc that Bloomer had proposed. Lavas similar to mid-ocean ridge basalt and ocean island basalt could have somehow erupted into the forearc. But all that is known about temperature distribution and magma composition in forearcs makes this scenario rather improbable.

The relation of the serpentine seamounts to potentially accreted frag-



CHIMNEY STRUCTURES on Mariana seamounts offer evidence for the escape of fluids carried up from the mantle. Chimney rocks and seeping fluids bear chemical traces that rule out seawater origins.



ROCK-STREWN FLOW FIELD on the flanks of Conical Seamount results from cold mud volcanism. The composition of most rocks matches that of the mud, but a few rocks show signs of mid-ocean rift or ocean island origin.

ments of oceanic plate could not be explained by any widely accepted theories of the behavior of convergent plate margins. As a result, the international marine geologic community decided to single out the Mariana seamounts for detailed study in the international Ocean Drilling Program. In 1989 Julian A. Pearce of the University of Durham in England and I led a team of 27 scientists from 10 countries on a cruise to drill a series of holes in the forearc regions of the Mariana and Izu-Bonin subduction systems immediately north of the Mariana Trench.

We drilled boreholes into Conical Seamount on the flanks and at the summit. Cores taken on the flanks to a depth of 313 meters below the seafloor recovered a complex series of serpentine flows. They contain not only serpentinized peridotite but also fragments of metamorphosed mid-ocean ridge basalt. This basalt suggests that the rising serpentine muds may have penetrated a fragment of accreted oceanic plate. In addition, muds recovered from the flank sites display abundant plastic folding and repeated shearing, suggesting that they were emplaced by eruption or slumping and that the seamount probably underwent significant postdepositional deformation.

Michael J. Mottl of the University of Hawaii analyzed the water in the pores of the muds. He found it to be indicative of seawater, present in variable proportions in the shallow flows of the flanks, and of a nonseawater fluid that reached extremes of composition in the summit sites near the suspected conduit of the seamount. He showed that trends in the composition of pore water from different locations were similar to those in the vent waters collected in our *Alvin* dives, but with an even more extreme deviation from seawater.

CORE of serpentine mud (actual size) was folded and sheared repeatedly after deposition.

Furthermore, these data make it clear that the relative abundances of the various compounds and elements in these fluids cannot be solely the result of interactions between seawater and the source rock of the serpentine. The fluids must have another source, and most likely it is the subducted slab.

When I analyzed the minerals in the muds, I found several that belonged to a rare carbonate-hydroxyl hydrate family, the sjogrenite group. On land, these minerals appear in serpentine outcrops that interact with water. The presence of these minerals in the seamount muds supports the role of the nonseawater fluid in the metamorphic process. If some of these minerals are to remain stable in the muds, the original fluids entrained must remain trapped in the mud flows during the entire process of emplacement and subsequent burial.

The mineral composition of the muds drilled varies subtly with depth, suggesting that the mud volcano undergoes pulses of activity interspersed with dormant periods. Conical Seamount is located at the intersection of at least two major faults and may be forming as movement along these faults grinds serpentinized peridotite into rock flour, which is transported to the surface as fluids from great depths escape along the fault planes. Variations in its activity may relate to movement along underlying faults and the variations in composition to differences in rock types at the fault foci. Dating of sediments recovered in the boreholes places the oldest flows that we drilled on the seafloor about a million years ago, indicating that the seamount probably formed relatively recently.

How many such mud volcanoes there may be, how many serpentine seamounts are formed by other means, and how many fractures in the forearc may be sites for active venting or seeping of fluids are all unknown. What is certain is that fluids and various components introduced into the forearc from the subducted plate make their way back to the ocean and return to the marine geochemical cycle.

The discovery of serpentine mud volcanoes in the Mariana forearc and the understanding of their origin have implications well beyond a single subduction zone. Geologists are identifying more and more exotic terranes (fragments of lithosphere) exposed on continents and islands in zones where plates collide, and many such terranes contain large serpentine bodies. These masses of serpentine are now being recognized as similar in structure and composition to the ones we found.

Study of serpentine in exotic terranes will make it possible to estimate the relative importance of serpentine diapirs and mud volcanoes in ancient forearcs. That knowledge, in conjunction with studies of modern serpentine seamounts, should help geologists comprehend the evolution of subduction zones throughout the earth's history. In addition, the comparisons of ancient exotic terranes on land to active forearc regions will continue to add to the understanding of the complex continental margins of which those forearcs frequently become a part.

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Cancer Cell Invasion and Metastasis

The most life-threatening aspect of cancer is the undetected spread of tumor cells throughout the body. Improved understanding of how these cells invade tissues is leading to new treatments

by Lance A. Liotta

Suppose that during a routine mammography screening, a 55-year-old woman learns she has a suspicious lump in her breast. With a microscope and a sample of the tissue mass, a pathologist can readily diagnose whether the tissue is malignant. The fate of the patient is far more difficult to determine, however. It depends on a cellular event that cannot be observed directly: metastasis, the spread of malignant cells throughout the body that induces secondary tumors.

When a cancer treatment fails, metastasis is the primary cause of death. If a primary tumor is detected early and removed before metastasis occurs, the cancer will be eradicated. On the other hand, if even microscopic metastases, or secondary tumors, are already present at the time of diagnosis, then the prognosis is grave. Left untreated, those metastases will grow and prove fatal.

Although the ominous nature of metastasis is well known, its sheer complexity as a process has historically impeded research progress. Fortunately, tenacious analysis of the individual steps of metastasis has finally yielded a wealth of new information. One of the most important findings is that, contrary to some early assumptions, metastasis is an active process and not an accidental consequence of tumor growth. Indeed, the invasion of healthy tissues by tumor cells—a critical step in the development of secondary tumors—is clearly a complex phenomenon that involves responses by both cancerous and normal cells.

Our laboratory at the National Cancer Institute (NCI) has been attempting to study the fundamental basis for cancer invasion and metastasis at two levels: the biochemical machinery of invasion that operates at the cell surface and the genes inside the tumor cell that make metastasis possible. Our combined approach involved direct observation of the behavior of individual tumor cells, extraction and purification of proteins produced by tumor cells, and isolation of genes expressed predominantly or exclusively in cells with either great or little metastatic activity. We have identified a set of genes and proteins that appear to regulate aspects of invasion and metastasis.

Those discoveries are now guiding us toward treatment strategies that might arrest tumors before they metastasize. Promising novel markers are being developed to predict the existence of small metastases that have not yet produced symptoms. Both those outcomes will help cancer patients in the early stages of their illness. A more pressing need, however, exists for techniques capable of eradicating secondary tumors that already exist. Our understanding of biomolecular mechanisms in metastasis seems to be leading us toward that goal as well.

The term "metastasis" was coined by Joseph Claude Recamier, a French physician, in his 1829 treatise *Recherches du Cancer.* He was the first to provide anatomic evidence that metastases are caused by cancer cells that enter the circulation and travel to distant sites in the body. Before Recamier, surgeons and anatomists had recognized that tumors could extend the borders of their growth to colonize nearby tissues and lymph nodes, but they believed that colonies of tumors in more distant organs arose independently. Recamier described local infiltration, invasion of veins by cancer tissue and secondary growths in the brains of patients with breast cancer.

Recamier's contributions to the biology of metastasis established his place in history, but they did not lead him to devise better therapies. He espoused compression wrapping as a treatment for breast cancer—presumably to restrain the spread of the tumor. We now know that procedure would actually promote the discharge of cancer cells into the circulation. Fortunately, treatment by compression never became popular.

More recent studies of metastasis have revealed it as an arduous, multistage marathon in which only a tiny percentage—fewer than one in 10,000—of the tumor cells that leave the primary tumor survive to start new tumor colonies. The competition begins when

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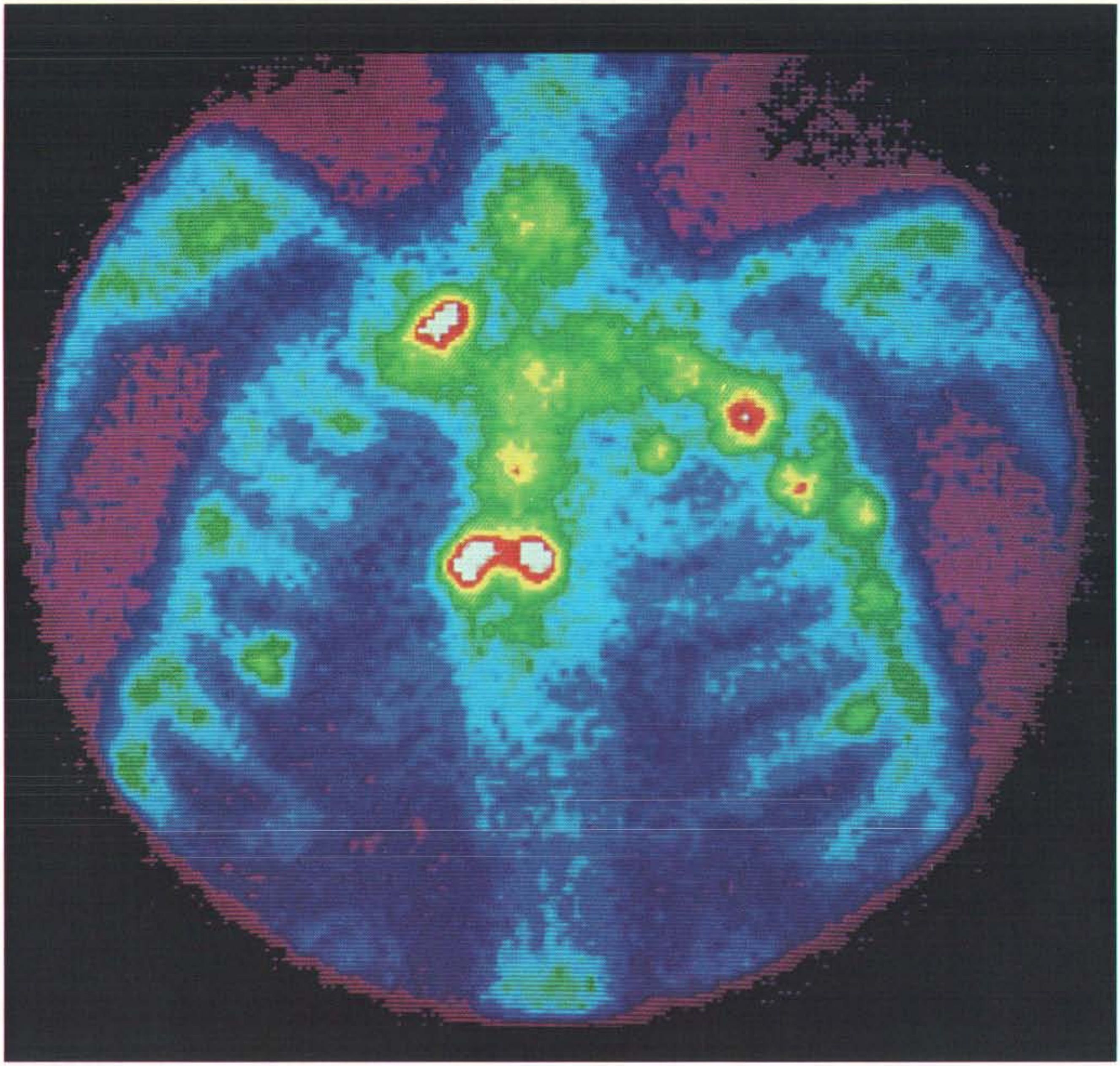
SECONDARY TUMORS, or metastases, appear as small colored "hot spots" against the background blue of a cancer patient's chest in this radioisotope scan. They are the result of tumor cells that separated from the primary mass and invaded more distant tissues. Researchers are beginning to understand the mechanisms that allow cells to migrate and are trying to find ways to interfere with that process.

tumor cells exit from the primary tumor by penetrating the walls of channels in the vascular and lymphatic circulatory systems. Tumors induce their own supply of new blood vessels (a process called angiogenesis) to nourish the rapidly expanding mass [see "The Vascularization of Tumors," by Judah Folkman; SCIENTIFIC AMERICAN, May 1976]. Because newly formed blood vessels in tumors are leaky, malignant cells can cross their walls fairly easily. Any branch of the vascular tree within a tumor mass is a potential site for the discharge of cells into the circulation.

Lymphatic vessels are also ports of entry for malignant cells, but tumors do not induce their own lymphatic network. Because lymphatic vessels normally drain away excess fluid between cells, the lack of lymphatics in tumors may contribute to the buildup of hydrostatic pressure within the tumor mass, as Pietro Gullino of the Institute of Anatomical Pathology in Turin first demonstrated. This internal pressure may actually hurt the tumor and help its host by shutting down weak vascular channels and depriving sections of the tumor mass of oxygen and nourishment. The absence of internal tumor lymphatics also means that cancerous cells can enter the lymphatic system only at the interface between the tumor and the host.

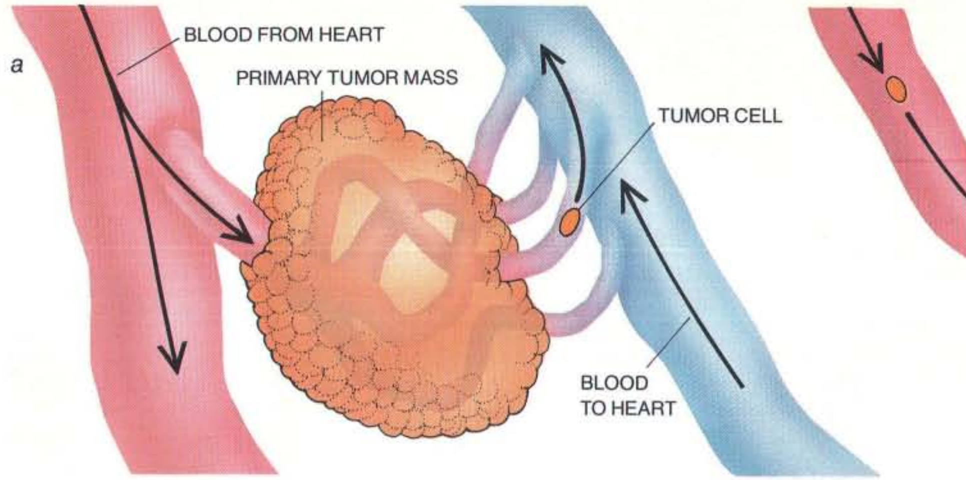
Tumor cells are usually carried in the venous and lymphatic circulation until they lodge in the next "downstream" capillary bed or lymph node, either by obstructing a narrow vessel or by adhering to the vessel's inner lining. In most cases, a metastasizing cell passes through the heart before it finds a resting place. Purely on the basis of circulatory anatomy, one can predict where 60 percent of the metastases from a primary tumor will arise. The lungs are a common site of metastasis for many cancers, for example, because the heart pumps all the blood through their capillaries before sending it elsewhere in the body. Metastases from colon cancer often arise in the liver, because the liver receives the direct drainage of venous blood from the large intestine.

When metastases arise in organs other than those predicted, it is usually be-



How a Cancer Can Spread

Metastasis, in which tumor cells colonize distant organs, is a multistage process. First, cells detach from the primary tumor mass and move into the blood vessels that nourish it (*a*). They are carried in the general circulation until they lodge in a capillary bed. Cells that survive this trip may then penetrate the blood vessel wall, invade the surrounding tissues and begin to proliferate (*b*). The new tumor mass can induce the growth of new blood vessels (*c*), which may eventually become departure points for more metastasizing cells.



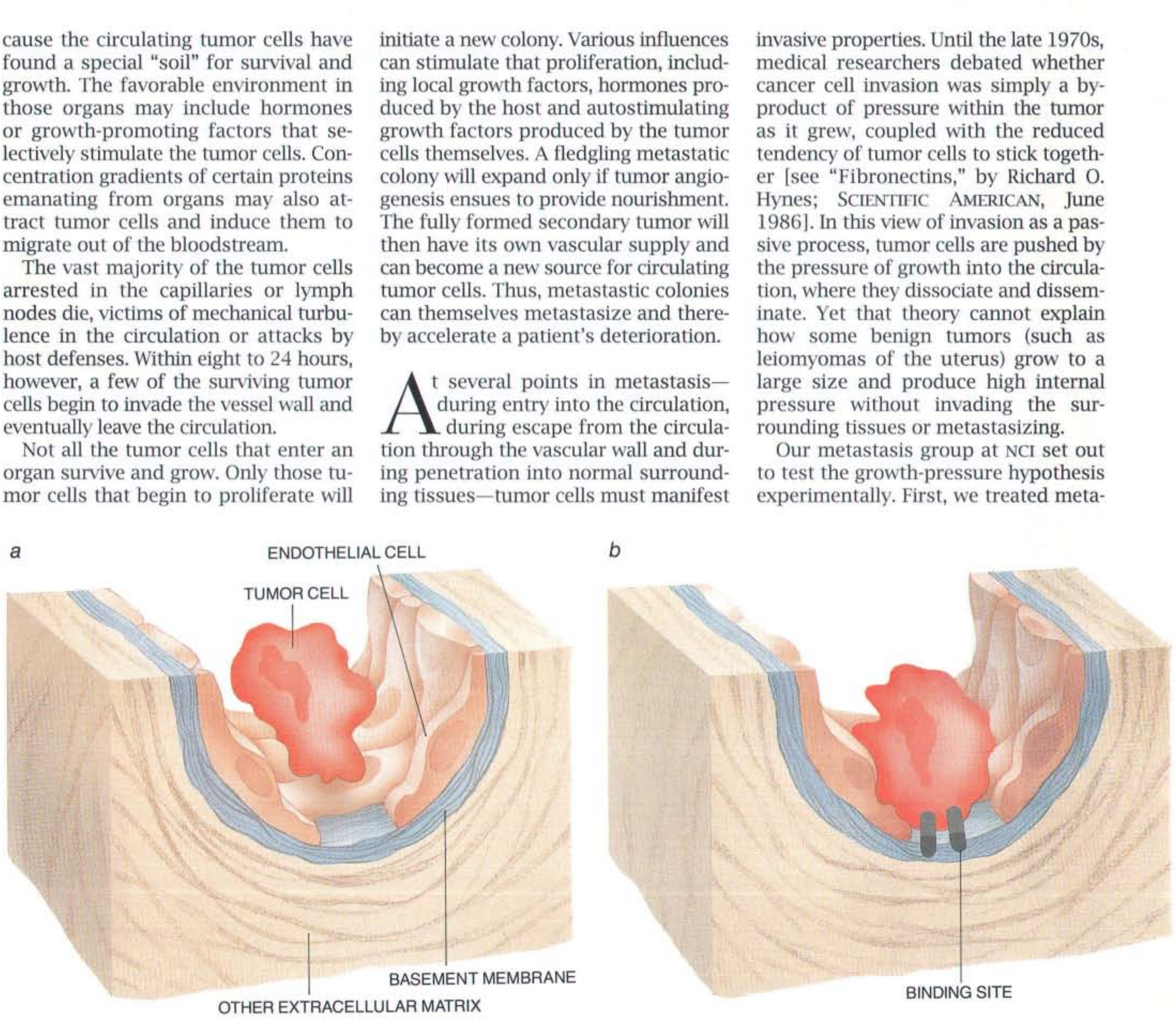
cause the circulating tumor cells have found a special "soil" for survival and growth. The favorable environment in those organs may include hormones or growth-promoting factors that selectively stimulate the tumor cells. Concentration gradients of certain proteins emanating from organs may also attract tumor cells and induce them to migrate out of the bloodstream.

The vast majority of the tumor cells arrested in the capillaries or lymph nodes die, victims of mechanical turbulence in the circulation or attacks by host defenses. Within eight to 24 hours, however, a few of the surviving tumor cells begin to invade the vessel wall and eventually leave the circulation.

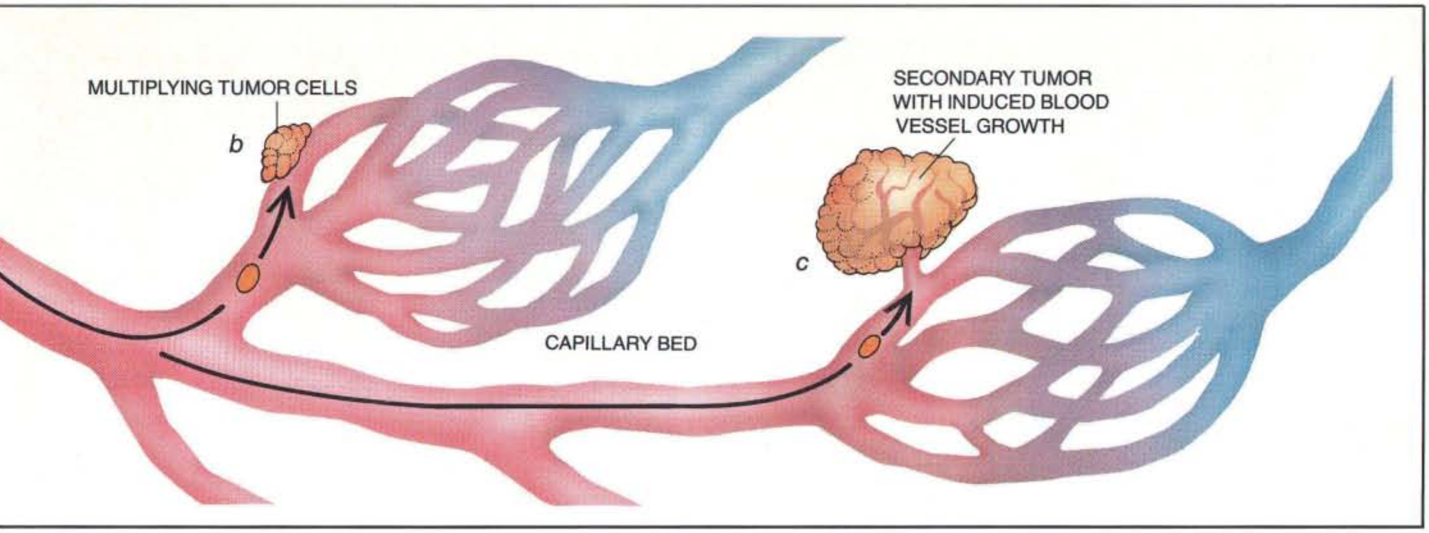
Not all the tumor cells that enter an organ survive and grow. Only those tumor cells that begin to proliferate will initiate a new colony. Various influences can stimulate that proliferation, including local growth factors, hormones produced by the host and autostimulating growth factors produced by the tumor cells themselves. A fledgling metastatic colony will expand only if tumor angiogenesis ensues to provide nourishment. The fully formed secondary tumor will then have its own vascular supply and can become a new source for circulating tumor cells. Thus, metastastic colonies can themselves metastasize and thereby accelerate a patient's deterioration.

At several points in metastasis—during entry into the circulation, during escape from the circulation through the vascular wall and during penetration into normal surrounding tissues—tumor cells must manifest invasive properties. Until the late 1970s, medical researchers debated whether cancer cell invasion was simply a byproduct of pressure within the tumor as it grew, coupled with the reduced tendency of tumor cells to stick together [see "Fibronectins," by Richard O. Hynes; SCIENTIFIC AMERICAN, June 1986]. In this view of invasion as a passive process, tumor cells are pushed by the pressure of growth into the circulation, where they dissociate and disseminate. Yet that theory cannot explain how some benign tumors (such as leiomyomas of the uterus) grow to a large size and produce high internal pressure without invading the surrounding tissues or metastasizing.

Our metastasis group at NCI set out to test the growth-pressure hypothesis experimentally. First, we treated meta-



INVASION is the complex process that allows tumor cells to escape from the circulation and establish metastases in tissues. As a prelude to invasion, a tumor cell induces the endothelial cells that line the blood vessels to retract, exposing the matrix of proteins called the basement membrane (*a*). The tumor cell then attaches to the basement membrane by



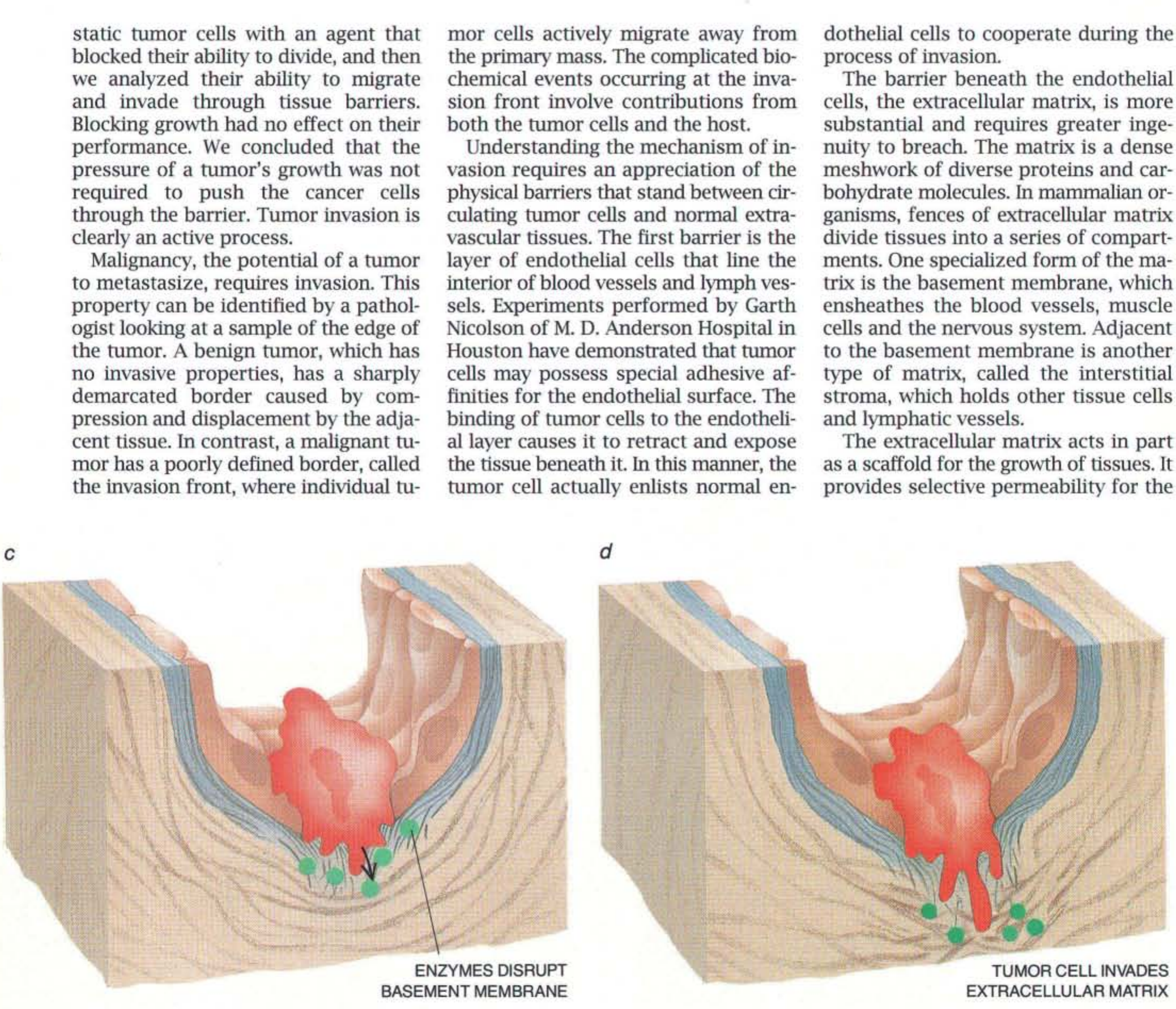
static tumor cells with an agent that blocked their ability to divide, and then we analyzed their ability to migrate and invade through tissue barriers. Blocking growth had no effect on their performance. We concluded that the pressure of a tumor's growth was not required to push the cancer cells through the barrier. Tumor invasion is clearly an active process.

Malignancy, the potential of a tumor to metastasize, requires invasion. This property can be identified by a pathologist looking at a sample of the edge of the tumor. A benign tumor, which has no invasive properties, has a sharply demarcated border caused by compression and displacement by the adjacent tissue. In contrast, a malignant tumor has a poorly defined border, called the invasion front, where individual tumor cells actively migrate away from the primary mass. The complicated biochemical events occurring at the invasion front involve contributions from both the tumor cells and the host.

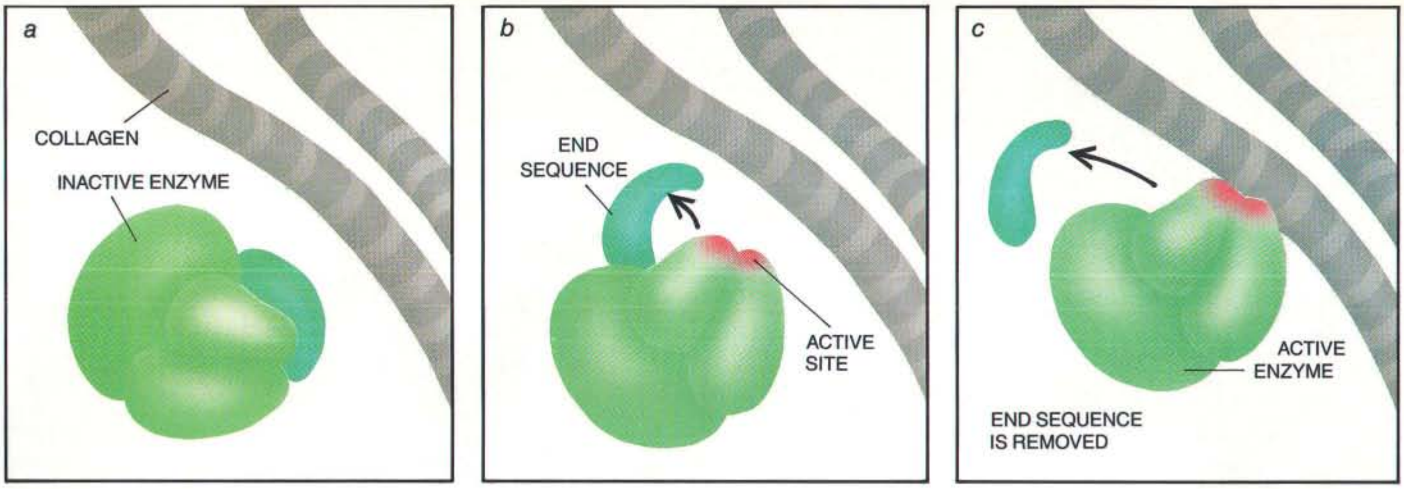
Understanding the mechanism of invasion requires an appreciation of the physical barriers that stand between circulating tumor cells and normal extravascular tissues. The first barrier is the layer of endothelial cells that line the interior of blood vessels and lymph vessels. Experiments performed by Garth Nicolson of M. D. Anderson Hospital in Houston have demonstrated that tumor cells may possess special adhesive affinities for the endothelial surface. The binding of tumor cells to the endothelial layer causes it to retract and expose the tissue beneath it. In this manner, the tumor cell actually enlists normal endothelial cells to cooperate during the process of invasion.

The barrier beneath the endothelial cells, the extracellular matrix, is more substantial and requires greater ingenuity to breach. The matrix is a dense meshwork of diverse proteins and carbohydrate molecules. In mammalian organisms, fences of extracellular matrix divide tissues into a series of compartments. One specialized form of the matrix is the basement membrane, which ensheathes the blood vessels, muscle cells and the nervous system. Adjacent to the basement membrane is another type of matrix, called the interstitial stroma, which holds other tissue cells and lymphatic vessels.

The extracellular matrix acts in part as a scaffold for the growth of tissues. It provides selective permeability for the


c
d
ENZYMES DISRUPT BASEMENT MEMBRANE
TUMOR CELL INVADES EXTRACELLULAR MATRIX

binding with certain molecules on it (*b*). Enzymes secreted by the cell cleave the matrix proteins and cut a hole in the membrane (*c*). The tumor cell then moves into the hole while continuing to produce more enzymes that allow it to penetrate the layers of extracellular material beyond the basement membrane (*d*) and to enter the tissues.

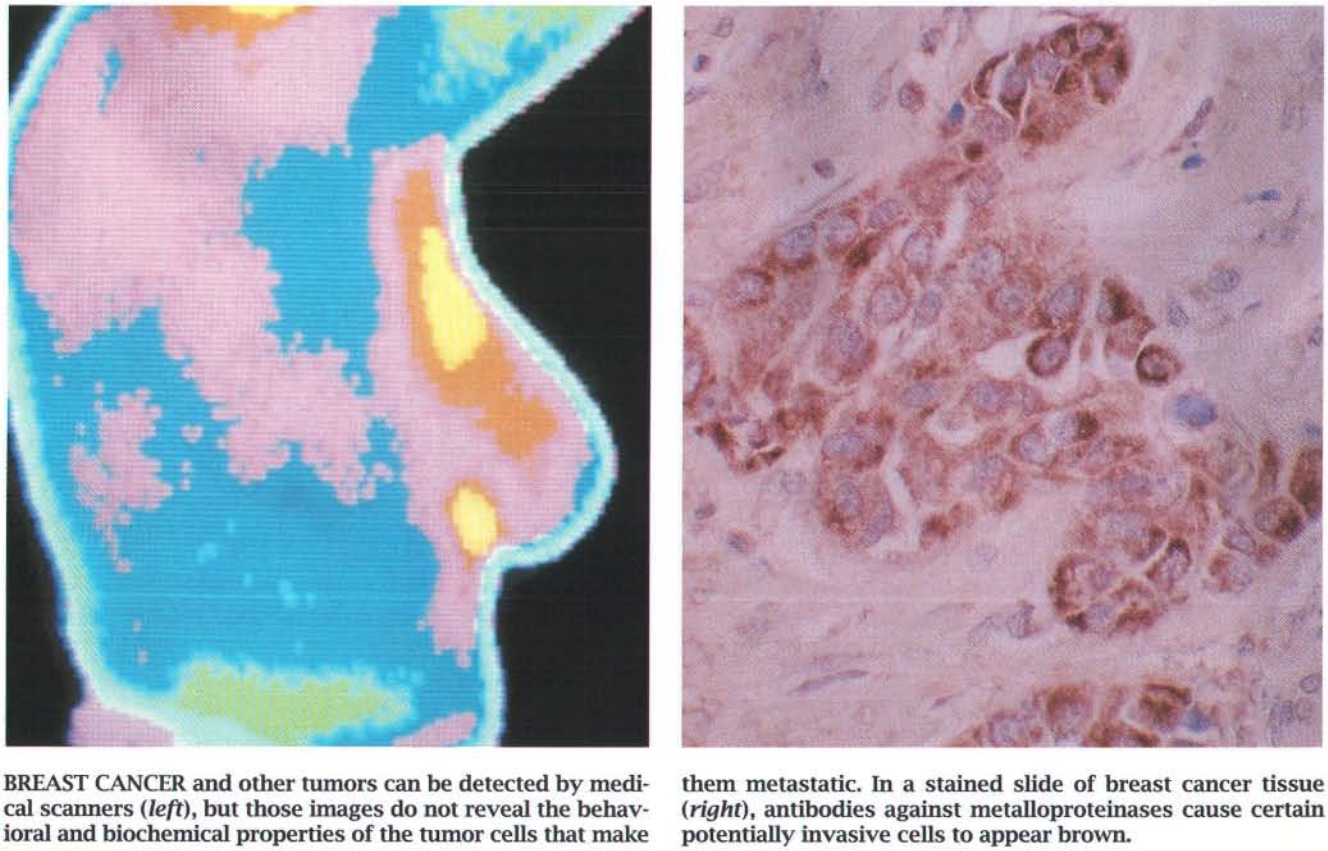


METALLOPROTEINASES are enzymes secreted by tumor cells that play a critical role in the invasion process. Initially, metalloproteinases are inactive because one end of the molecule obstructs the active site of the enzyme (*a*). When the enzyme is needed, however, the end sequence is pulled aside and clipped off (*b*). With its active site clear, a metalloproteinase

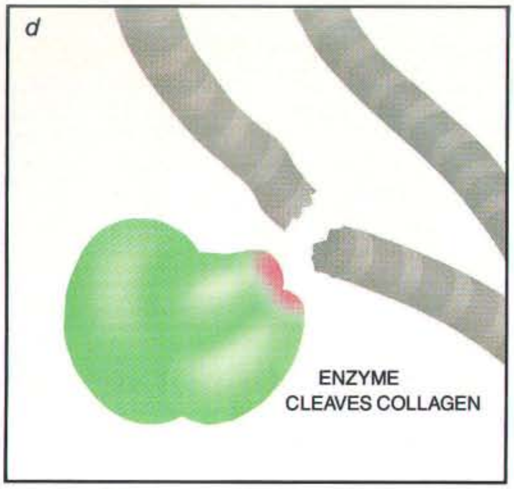
transport of proteins and other molecules between cells, across blood vessel walls and during filtration by the kidney. Moreover, the extracellular matrix also serves as a mechanical barrier to tumor cell invasion.

Normally, the cellular populations on either side of the extracellular matrix do not intermix, even during wound healing or organ development in the embryo. Malignant cells, however, traverse the extracellular matrix readily, cross tissue boundaries and end up where they do not belong. The disruption of basement membranes is a hallmark of the invasion front in all human cancers. A "social order" definition of the metastatic tumor cell is its tendency to disrupt extracellular matrix boundaries and to intermix with cell types different from those found in the original tumor bed.

The continuous basement membrane that surrounds blood vessels does not usually contain pores or channels large enough for tumor cells to traverse it passively. Metastasizing tumor cells must therefore find another way to penetrate the basement membrane and escape from the circulation. To study that process, my colleagues and I extracted basement membranes from animal tissues. When metastatic tumor cells were placed on the isolated basement membranes, they attached avidly. Beneath the attached tumor cells, a zone of ly-



BREAST CANCER and other tumors can be detected by medical scanners (*left*), but those images do not reveal the behavioral and biochemical properties of the tumor cells that make them metastatic. In a stained slide of breast cancer tissue (*right*), antibodies against metalloproteinases cause certain potentially invasive cells to appear brown.



bound to a collagen molecule in the extracellular matrix (*c*) can cleave the protein into fragments (*d*).

sis then formed in which basement membrane proteins fragmented. Finally, the tumor cells migrated into and penetrated the disrupted region of the basement membrane.

From these results, we determined that the invasion of the basement membrane barrier is a three-step process. The first step is the adhesion of the tumor cell to the basement membrane. The adhesion is mediated by specific receptors on the tumor cell surface that recognize components of the basement membrane. The second step is the activation of destructive enzymes that cleave or unravel basement membrane molecules immediately beneath the tumor cell. The third step is the protrusion of the tumor cell's pseudopodia (amoeboid false feet) into the zone of lysis, followed by migration of the entire tumor cell.

The three steps of tumor cell invasion—adhesion, enzymatic modification of the membrane and migration—must be tightly coordinated and properly timed. While the advancing front of the tumor cell surface activates destructive enzymes to cleave obstructing protein molecules, the rear of the tumor cell must remain firmly attached to the extracellular matrix. Once the path ahead is opened, the tumor cell has to switch activities so that the enzymes are turned off and the cell can advance. This switch is necessary because, to move forward, the invading tumor cell must grab onto the matrix in the direction of travel, pull itself forward and release any attachments at the rear of the cell. In other words, an invading tumor cell must simultaneously bore a tunnel, grip the sides of the tunnel and propel itself forward.

That striking behavior is not unique to metastatic cancer cells: from time to time, normal cells, too, must invade other tissues in the body. Normal invasive behavior occurs, for example, during the implantation of the placenta in the wall of the uterus and during the formation of organs in the embryo. Circulating white blood cells must penetrate the walls of blood vessels to reach a site of infection. Networks of blood vessels are established by the migration and invasion of endothelial cells—they pass through extracellular matrix barriers and enter regions of tissues that require the nutrients and oxygen a new vascular system can supply.

In all these cases, the mechanism of invasion by the normal cells is likely to be generally the same as that used by tumor cells. There is nonetheless a crucial difference in the regulation of the processes: when the stimulus for a normal invasion is removed, the cells stop. Malignant cells can migrate relentlessly and penetrate tissue barriers at times and places that would be inappropriate for normal cells.

Questions about how normal cells and metastatic tumor cells are regulated prompted my colleagues and me to search for genes and proteins characteristically associated with invasion. We have met with some success. One surprising result of our studies was that negative regulatory proteins—those that inhibit invasive behavior in normal and cancerous cells—may be just as important as positive factors that promote aggressiveness. That discovery has led us to propose the existence of metastasis suppressor genes: genes that encode proteins capable of suppressing the key steps of metastasis.

The concept of genes that suppress metastasis parallels the recent work by Robert Weinberg of the Whitehead Institute and Bert Vogelstein of Johns Hopkins University, who have shown the importance of genes that suppress cancer cell growth. Weinberg and Vogelstein proposed that the loss or mutation of certain regulatory genes, such as the p53 gene and the retinoblastoma gene, will lead to abnormal, uncontrolled cell growth—the first step in the development of a cancer. The next critical step is the transition of the tumor from mere growth to invasion and metastasis.

During that transition, some genetic events cause tumor cells to increase their production of proteins that stimulate migration and enzymes that cleave the extracellular matrix. Those same cells may also stop expressing metastasis suppressor proteins that usually block benign tumor cells from turning into metastatic ones.

To identify enzymes important for invasion, we compared the enzymes produced in cultures of metastatic invasive cells with those of nonmetastatic tumor cells. We took advantage of cancer cell lines isolated by Isaiah Fidler of M. D. Anderson Hospital, the scientist who first systematically produced lines of mouse tumor cells with different metastatic propensities. Highly invasive tendencies, we observed, were associated with the increased production of a class of protein-cleaving enzymes called metalloproteinases. After extending the studies to human cancers, we found that augmented levels of metalloproteinases in tumors correlated with the development of invasion and metastasis in cancers of the human breast, colon, stomach, thyroid, lung and liver.

At least eight members of the metalloproteinase gene family have been found so far. All the metalloproteinases have similar structures, but they differ significantly in the types of protein they cleave. One important protein cut by the metalloproteinases, for example, is collagen, a rod-shaped triple helical molecule that forms the framework for the extracellular matrix. One variety, called type IV collagen, makes up the structural backbone of the basement membrane barrier. Other types of collagen are characteristically found in other tissues. Tumor cells therefore probably need to use more than one metalloproteinase, as well as other classes of destructive enzymes, to cross the varied tissue barriers they encounter.

To prove that metalloproteinases were actually necessary for invasion, we treated tumor cells with antibodies that selectively blocked the activity of certain members of the metalloproteinase family. The antibodies totally abolished the invasive action of the tumor cells in our tests.

Much of what has been learned about the structure and function of the metalloproteinases could someday lead to the development of drugs that prevent or arrest invasion and metastasis by blocking the action of the enzymes. For example, we know that all the metalloproteinases are produced in an inactive form completely incapable of cleaving any protein molecule. The inactivity of that form is caused by a highly conserved sequence of nine amino acids found at one end of all the metalloproteinase molecules.

This sequence contains an extremely reactive residue of the amino acid cysteine. In the inactive form the end of the molecule containing the sequence folds, and the cysteine residue interacts with the metal ion in the active site of the enzyme. With its active site blocked in this way, the enzyme is unable to cleave its protein target. Thus, the metalloproteinases are made with their own built-in inhibitors.

A metalloproteinase becomes active when its molecular shape changes and the cysteine-containing peptide (or protein fragment) is pulled away from the ion in the active site. The metalloproteinase then snips off its own cysteine-containing peptide and becomes permanently active. My colleagues and I have studied the conformational changes of metalloproteinases in samples of human tumors, and we have found that the enzymes do shift into a form associated with full activity.

This knowledge about metalloproteinases should have practical value. One exciting possibility is that a drug mimicking the cysteine-containing peptide might be able to block metalloproteinase activity and thereby arrest or inhibit invasion and metastasis. Nevertheless, questions must still be answered concerning the problem of precisely what triggers the changes in the enzyme.

One possibility is that other types of degradative enzymes in the tumor cell can activate a latent metalloproteinase by cutting off its inhibitory peptide. Another possibility, recently proposed by William G. Stetler-Stevenson, my colleague in our metastasis research group, is that immobilized proteins on the surface of a tumor cell may activate the enzymes. These cell-surface activator proteins could provide the tumor cell with exquisite control over the local activity of the metalloproteinases.

Even an activated metalloproteinase, however, will fail to cleave its target if a powerful tissue inhibitor of metalloproteinase (TIMP) is present. Just as there is a family of metalloproteinases, there is also a family of TIMPs, with at least two members: the original TIMP-1 and the new TIMP-2, identified by Stetler-Stevenson. Both TIMPs can inhibit all the active metalloproteinases, but TIMP-2 has a further special affinity for the latent, or inactive, form of type IV collagenase, the metalloproteinase that cleaves type IV collagen.

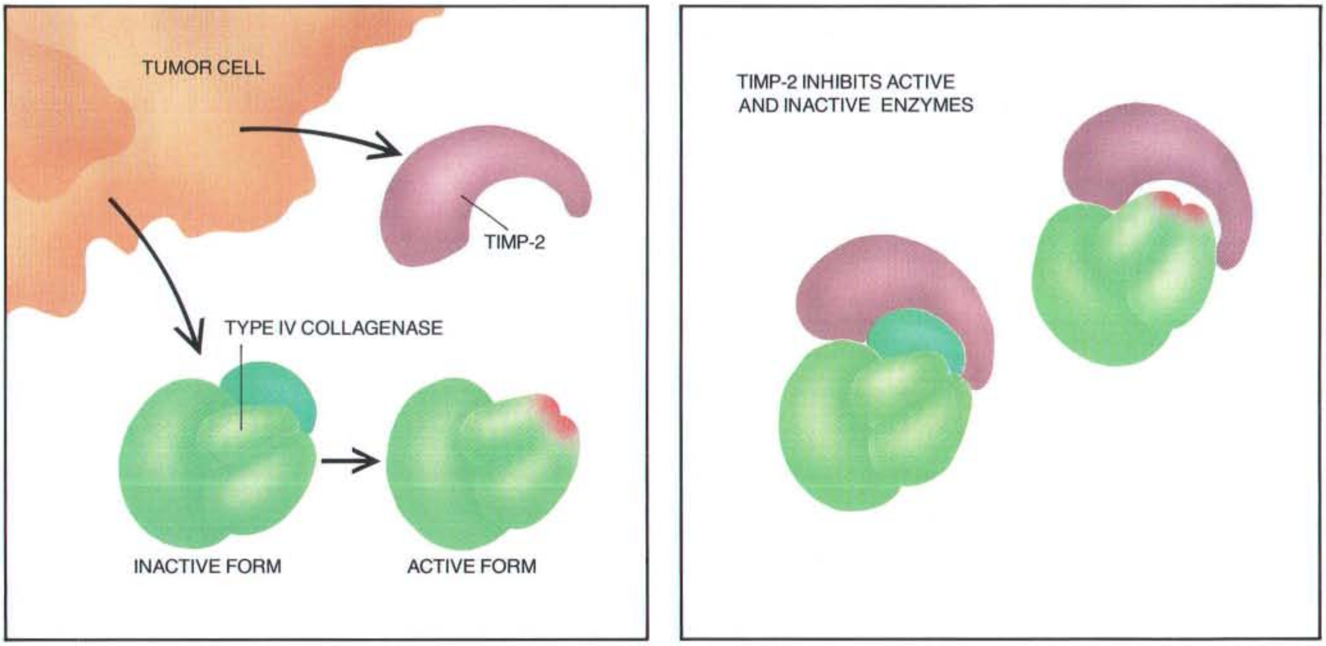
TIMPs produced in normal tissues, such as cartilage and bone, may have an important role in guarding against the excessive breakdown of the extracellular matrix. They may protect nerves from injury by preserving the basement membrane that surrounds nerve fibers. TIMPs also potentially serve as regulators of cell growth in the blood vessels and bone marrow.

Tumor cells, too, can secrete TIMPs: for instance, TIMP-2 is produced by many tumor cells. The same malignant cell that produces a metalloproteinase may therefore also produce an inhibitor of it. Enzyme function will occur only if the number of enzyme molecules is greater than the number of TIMP inhibitor molecules. Thus, in this and all other aspects of cancer cell invasion, the outcome depends on the balance of both positive and negative regulatory proteins.

TIMPs are therefore metastasis suppressor proteins. Several laboratories have shown that TIMP-1 and TIMP-2 can halt the process of tumor cell invasion. TIMP-2 can also block the formation of new blood vessels required to nourish the growing metastasis. These encouraging results mean that TIMPs, or drugs that act like them, may offer an approach to prevent invasion or treat metastasis.

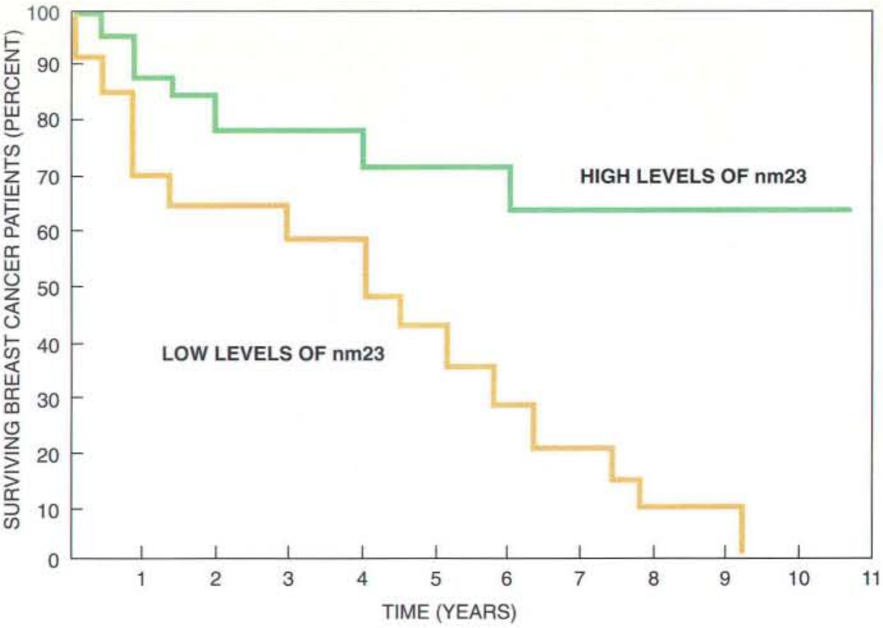
Another potential metastasis suppressor protein was recently discovered by Patricia S. Steeg of our metastasis research group. While screening for differences in genetic activity between metastatic and nonmetastatic mouse tumor cells, Steeg noticed that one gene was missing or inactive in the metastatic ones. The protein produced by the gene was consistently absent or deficient in many metastatic tumor cell lines and present at high levels in nonmetastatic tumor cells. That protein became known as nm23 (nonmetastatic 23).

Clinical studies conducted by our group in the U.S. and by Colm Hennessy of the University of Newcastle and Narimichi Kimura of the Tokyo Metropolitan Institute of Gerontology concluded that in a sample of primary breast cancers, low levels of nm23 were strikingly associated with metastasis and poor survival. Conversely, high lev-



TISSUE INHIBITORS OF METALLOPROTEINASE (TIMPs) are compounds secreted by cells that suppress invasion by preventing the breakdown of collagen. One member of the TIMP family, TIMP-2, is particularly effective because it binds with both the active and inactive forms of the metalloproteinase enzyme called type IV collagenase.

els of nm23 correlated with the absence of metastasis and a very favorable prognosis for the patients. Furthermore, more than half of the human breast cancers that could be analyzed for genetic alterations were missing one of the two copies of the nm23 gene. Indeed, normal breast tissue and noninvasive breast lesions have high levels of nm23. Alterations in nm23 therefore correlate strongly with the transition to invasion and metastasis. This pattern has been observed not only in breast cancer but also in other types of cancer.



SURVIVAL CURVES for breast cancer patients reflect the importance of the protein nm23, which seems to suppress metastasis. Patients whose tumor cells contain high levels of nm23 have few metastases and good prognoses. Conversely, patients with cells low in nm23 tend to die sooner because they have many metastases. Levels of nm23 could become important indicators for cancer treatments.

If adequate levels of normal nm23 protein offer protection against breast cancer, then measurements of nm23 in breast tumors could have clinical value. A significant number of women with newly diagnosed breast cancer have no clinical evidence of metastasis. Yet we know that approximately 25 to 30 percent of these patients have hidden metastases too small to produce symptoms. Measurements of nm23 and other biochemical indicators now under study may help pathologists identify patients most at risk for hidden metastases so that they can be treated in a timely fashion.

The nm23 protein may eventually play a part in treatment as well as in diagnosis. In the laboratory, Steeg inserted the gene for nm23 into cultured metastatic cells, thereby augmenting their expression of nm23. When these cells were injected into mice, they failed to form metastases. We can speculate that if the nm23 gene could be introduced into tumor cells in the body by some as yet undeveloped gene therapy, metastasis could be arrested.

How does nm23 inhibit metastasis? We know that the nm23 protein has enzyme activity that allows it to attach inorganic phosphate groups to protein molecules. Such phosphate groups can modify the activities of proteins, including those that regulate growth signals and differentiation. We also know that nm23 is not secreted out of the cell. Other than these facts, however, we still do not understand the function of the nm23 protein.

Perhaps the normal function of nm23 will be revealed through studies of its fascinating conservation through millions of years of evolution. Human nm23 is virtually identical to *awd,* a fruit fly protein studied by Allan Shearn of Johns Hopkins. In the fruit fly, *awd* is required for the correct formation of all the adult epithelial organs: the brain, the eyes, the wings, the legs and the reproductive organs. By analogy, we can speculate that nm23 has an important function in the normal organization and communication of human cells. During development, normal tissue cells communicate with one another to produce an organ that has the correct size and shape. The loss or aberrant regulation of nm23 may contribute to an unstable cellular state that favors the autonomous and metastatic behavior of tumor cells.

Predicting or preventing future metastasis is a very important clinical goal. One that is equally important but more urgent is the eradication of known metastases in cancer patients. Molecular studies of the communication pathways that regulate invasion and colony growth by tumor cells has led Elise Kohn, another member of our metastasis research group, to recognize a new class of synthetic compounds, called carboxyamide aminoimidazoles (CAIs).

When administered orally, CAIs block the growth of established metastases in animals. As Chris Felder of the National Institute of Mental Health and Donald Hupe of Merck & Co. have shown, CAI compounds alter the flow of calcium ions into the cell. We believe this change may interfere with the signals that stimulate the growth of metastatic colonies. Laboratory experiments have demonstrated that CAIs can arrest the growth of various human solid tumors, including melanomas (highly metastatic tumors of skin pigment cells) and cancers of the colon, breast and prostate.

By the time this article appears, phase I clinical trials of this new CAI treatment will have already started here at the National Cancer Institute. This is an exciting time for all students of metastasis and cell invasion: after more than a century and a half of research, medical science may finally be able to turn the understanding of metastasis to the good of patients. The range of approaches to the problem has never been wider, and the prospects for success have never been brighter.

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The Mammals of Island Europe

A mine at Messel in Germany has yielded magnificently preserved fossils of mammals that roamed Europe when it was an island. They clarify a key phase in evolutionary history

by Gerhard Storch

Fifty million years ago a lake covered what is now the mining pit at Messel, 20 kilometers from Frankfurt, Germany, and animals would come to drink of its deceptively still waters. They would linger by the shore, bathe in the shallows or cling to branches hanging over the water. Bats, in particular, were liable to be caught over the deeper sections while skimming the rippling surface in pursuit of insects.

Then, at intervals too long for the animals to take note of any pattern, a plume of poisonous gas would rush to the surface, asphyxiating any creatures it enveloped. (Such events are well documented: just six years ago a lake in Cameroon belched a cloud of carbon dioxide that killed thousands of people and animals.) Each outburst of gas from the lake at Messel would thus cast its net wide, sending a new harvest of animals into the depths. There the toxic conditions often preserved the soft tissues to an extraordinary degree—one can often make out a rodent's fur, a pangolin's scales, the bones of an animal's inner ear, even the contents of its last meal. The fossils fed a slowly growing slab of oil shale on the lake floor.

No other site has yielded so diverse an array of such beautifully detailed fossils from the Eocene, the period between 53 and 35 million years ago, when Europe was a subtropical island. The mammals of Messel, coming from the early middle Eocene, are particularly important because they afford a window on the most revolutionary period the European mammals ever saw: the early Eocene. Only very framentary fossils from that period have been found, but a reconstruction of the routes by which animals dispersed shows it was a time in which a primitive European fauna was exposed to a mass invasion of a modern fauna. The new mammals largely drove the natives to extinction, and most of the mammals at Messel are the descendants of these invaders.

Here I am mainly concerned with these "new" animals—their probable homelands, invasion routes and descendants. Such questions are the principal challenge to interpretation. The invaders' quick success over native forms, however, seems easier to understand. The newcomers would appear to have been more intensively selected, perhaps because their home ranges had harbored a more formidable complement of competing organisms. In any case, the new fauna made a more balanced army than the old. It included, for example, the first hoofed animals, both even toed and odd toed. These browsers seem to have occupied ecological niches that had previously been empty. Among the invaders were groups that later became very successful, notably the prosimians, founders of the primate order to which *Homo sapiens* belongs.

The animals provide a snapshot of a period some 500,000 to one million years long, the life span of the lake. By the end of the first quarter of the Eocene, the lake had dried up, and parts of its bed and the tributaries that had fed it were ground into dust by tectonic activity and natural erosion. Millions of years later much of the unscathed material was excavated by miners seeking oil-bearing shale. They left an open pit a kilometer long, 700 meters wide and 70 meters deep. Even that residuum was for many years in danger of being converted to a landfill, until in 1986 the state of Hesse declared Messel a natural preserve. This designation saved the site not only from the garbage trucks but also from those amateur paleontologists who had been plundering its treasures.

Suitable techniques for the preservation of the shale fossils were developed only 20 years ago. Since then, however, the discoveries at Messel have generally been recognized as having added a diverse stock of fossils to the debate over the origin and spread of systematic units (such as species and families). Messel has already yielded specimens from more than 40 mammalian species spanning 14 orders, a range that continues to grow as new materials are analyzed. Many have been reconstructed on the basis of preserved soft-body outlines and articulated skeletons; in such cases, everything but the coloration of the fur can be determined from the fossil. Others have been modeled by a process that may be likened to the unfolding of a crushed cardboard box. The products of such reconstructions appear beside many of the photographic plates in this article.

The new fauna that invaded Europe seems to have been isolated soon after its arrival, perhaps because the terrestrial routes of invasion were cut off. Moreover, parts of Europe were in many cases sequesterd from other parts by shallow arms of the sea, making it less an island than an archipelago. And as happened in modern archipelagoes, the colonizing mammals soon became lo-

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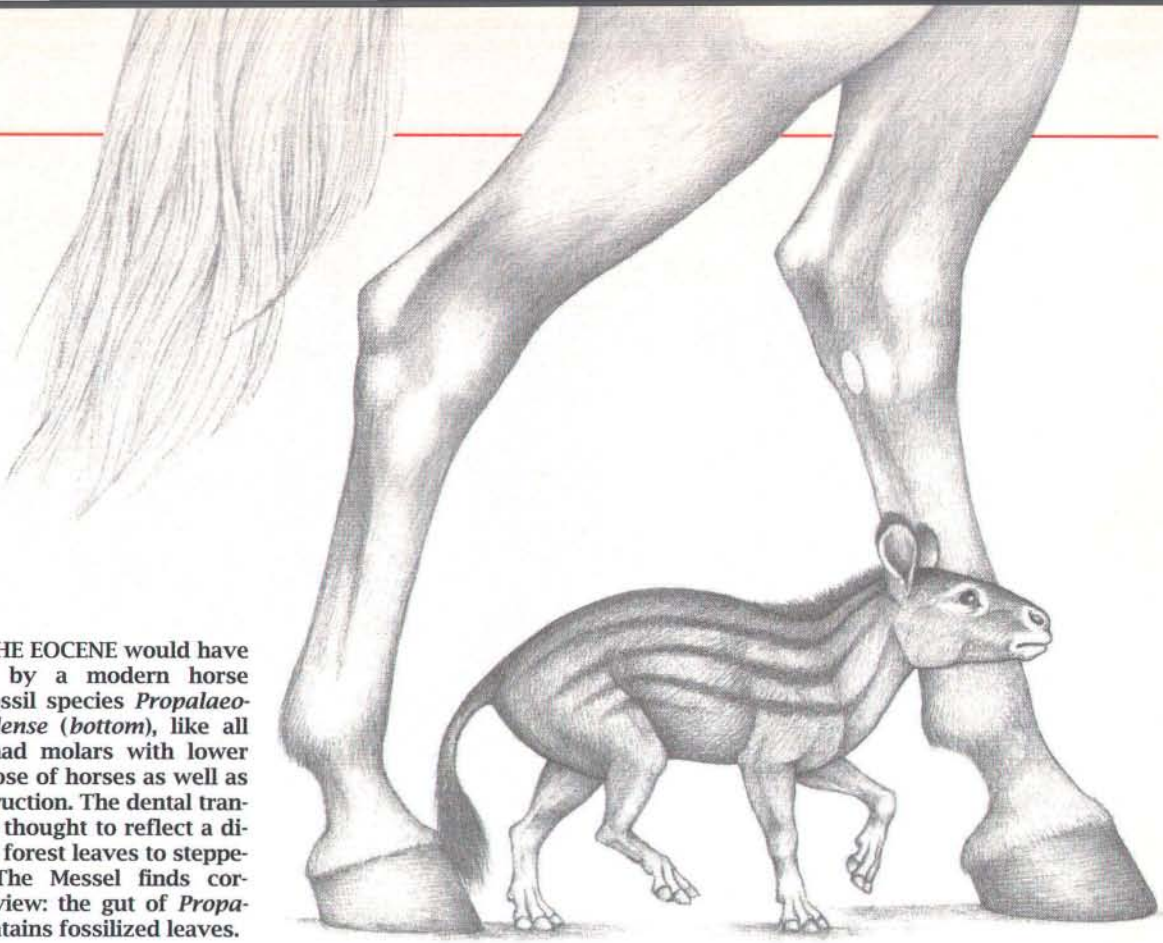
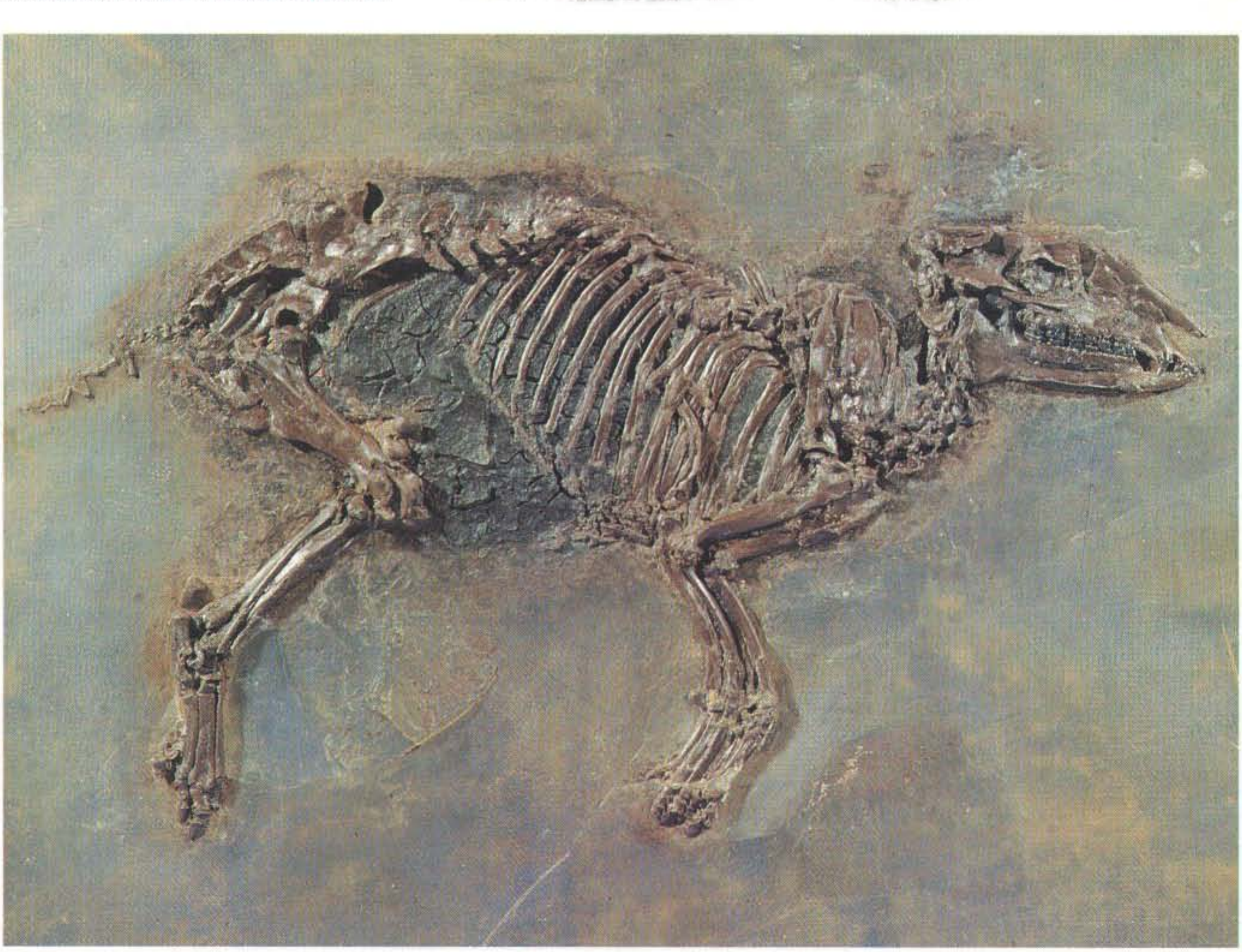


EQUID FROM THE EOCENE would have been dwarfed by a modern horse (*above*). The fossil species *Propalaeotherium messelense* (*bottom*), like all early equids, had molars with lower crowns than those of horses as well as a simpler construction. The dental transition had been thought to reflect a dietary shift from forest leaves to steppeland grasses. The Messel finds corroborated this view: the gut of *Propalaeotherium* contains fossilized leaves.



cally differentiated. Such differentiation—called endemism—appears even among species as mobile as bats (fossils of which are greatly overrepresented, suggesting that they often drowned in the lake). Endemism tends to erase the visible evidence of genealogical ties, making a few of the mammals from Messel hard to interpret.

Although the invading mammals clearly derive from lineages that originated outside Europe, exactly where is often a mystery. To answer the question, moreover, one must first ascertain which specimens derived from invaders and not from the handful of surviving indigenous Europeans. There is little evidence to go on. All that is known from the late Cretaceous—a period between 100 million and 65 million years ago—can be traced to a single molar from southern France and a few tooth fragments from Portugal.

The record is utterly blank for the early Paleocene, the period following the Cretaceous-Tertiary boundary 65 million years ago. The only possible known forerunners for native Europeans at Messel come from middle and late Paleocene sites in Belgium, the Paris Basin, and Walbeck in Germany. But these mammalian fossils are greatly endemic and archaic—none of them gave rise to modern, extant families. One species from Messel, however, is a likely candidate for the status of an archaic European native: *Leptictidium nasutum*, a bizarre bipedal mammal [*see illustration on this page*].

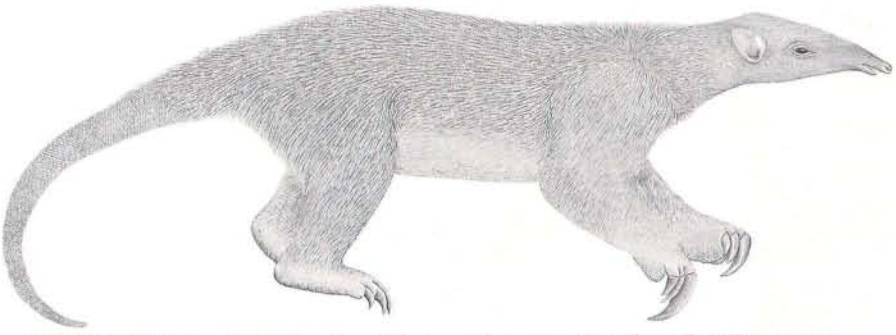
Where then did the newcomers originate? Asia is an unlikely source because it harbored a distinct fauna and was separated from Europe by a transcontinental seaway. Still, some species, such as the pangolins, may have breached the barrier.

North America—then cut off from South America—seems a more likely source for certain groups. Two land bridges connected that continent to Europe during the early Eocene, despite the expansion of the channel that later formed the North Atlantic. Favorable climate conditions would have afforded rather free passage to those mammals capable of negotiating all the ecological zones of the bridges. Indeed, some 60 percent of the genera known from the European early Eocene have also been identified in sediments of the Rocky Mountains. The dramatic faunal innovations of the early Eocene took place simultaneously in North America and Europe, and some experts define these areas as a common zoogeographic zone: Euramerica.

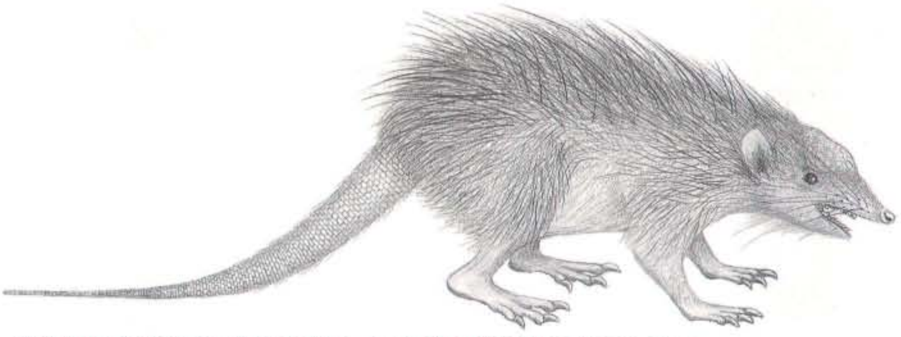
Most workers have presumed that

Recalled to Life

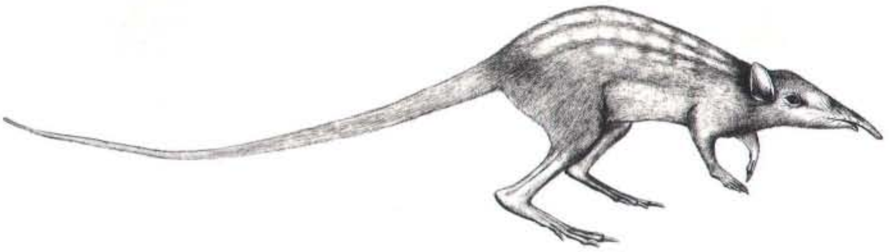
The fossils on the opposite page were reconstructed on the basis of soft-body outlines and articulated skeletons. All but the animals' colors can thus be recovered.



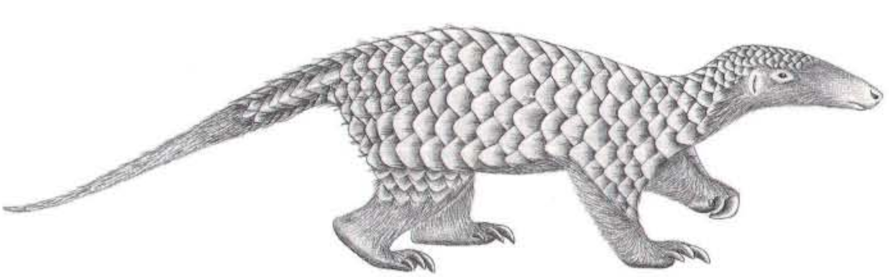
***EUROTAMANDUA JORESI*, the oldest and most complete fossil anteater yet found, was about 80 centimeters long (32 inches) from nose to tail.**



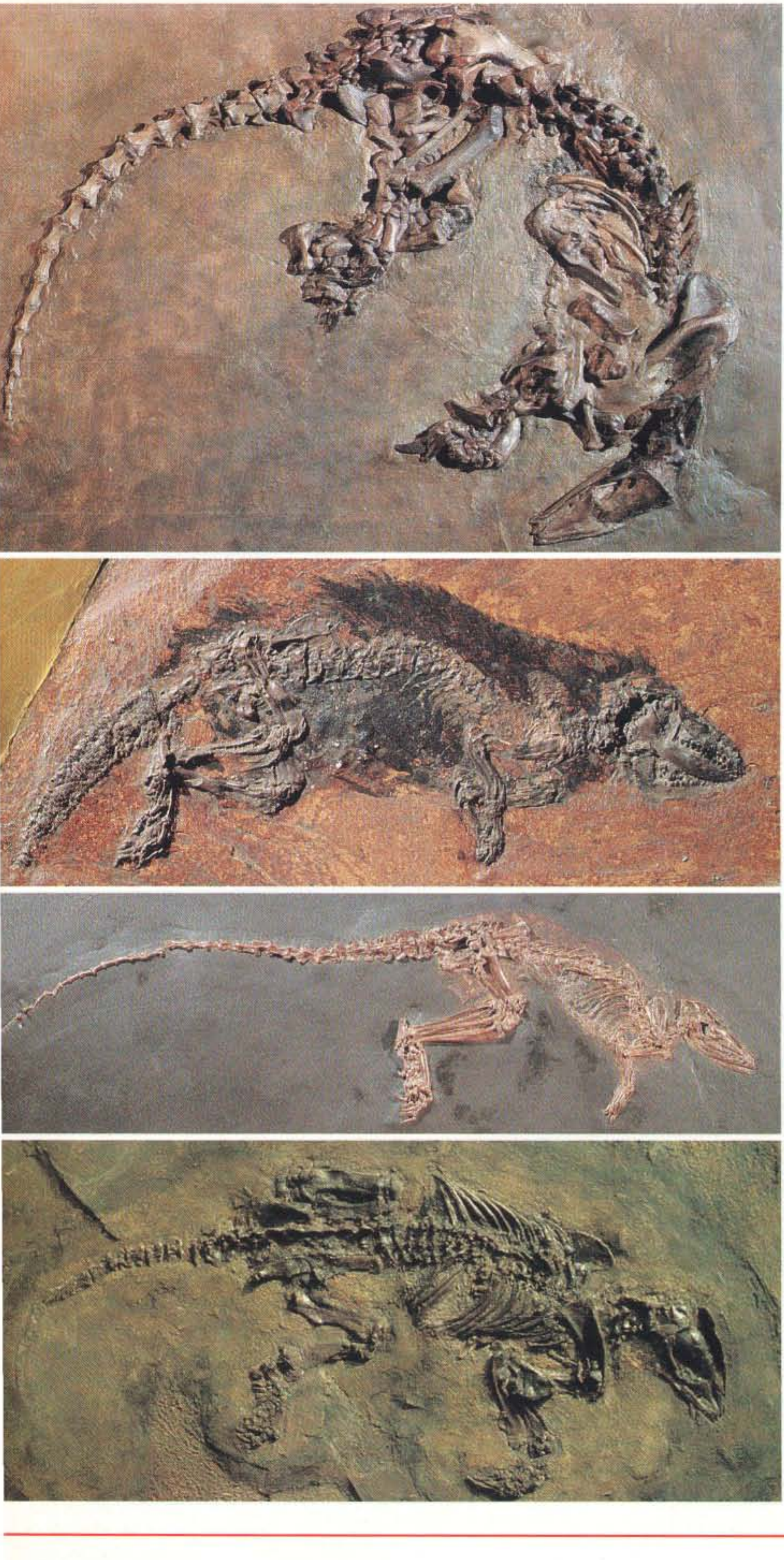
***PHOLIDOCERCUS HASSIACUS*, a hedgehoglike insectivore, was about 40 centimeters long (16 inches).**



***LEPTICTIDIUM NASUTUM* ran bipedally, unlike any living mammal save *Homo sapiens*. It measured 75 centimeters (30 inches).**



***EOMANIS WALDI*, the oldest known pangolin, resembles extant species. The 50-centimeter (20-inch) animal ate ants and termites.**



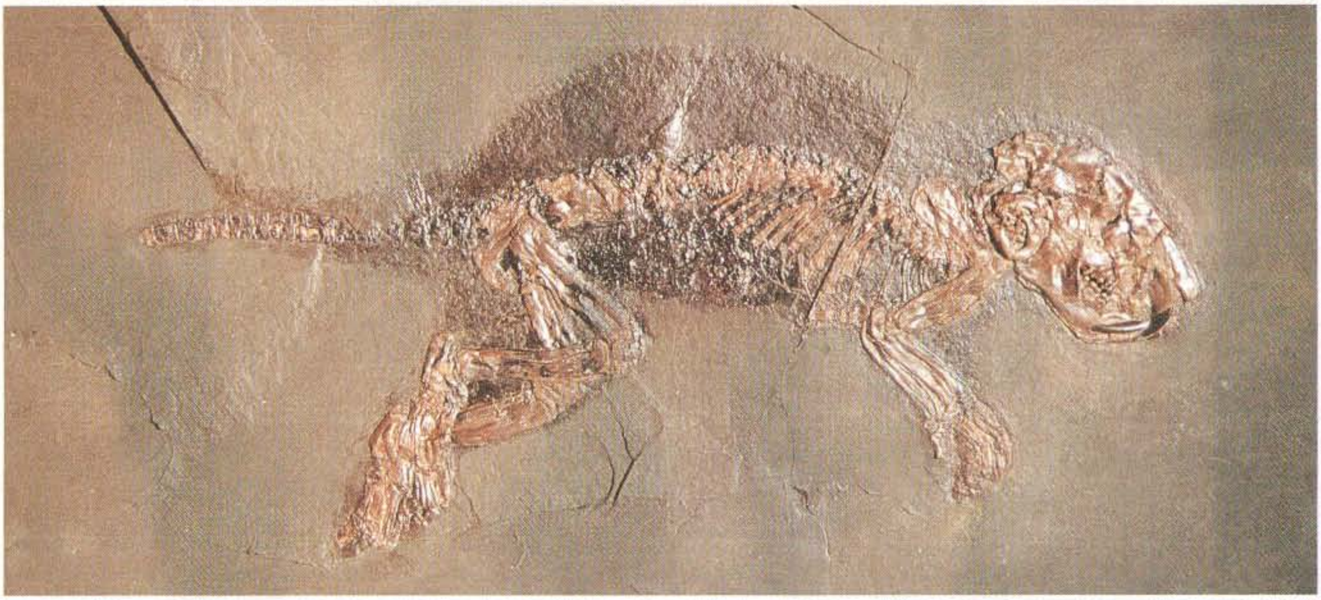
dispersal flowed mainly from North America to Europe, and in some instances this clearly happened. Modern carnivores, for example, seem to have originated in North America. Their stem group, the miacides, appear in U.S. sites from the early Paleocene but do not crop up in Europe until the Lower Eocene, some 10 million years later. Rodents also took this route to Europe, but, unlike carnivores, they arrived in North America only a short time before reaching Europe. This schedule suggests that the rodents had originated in Asia and crossed into North America on the Bering land bridge.

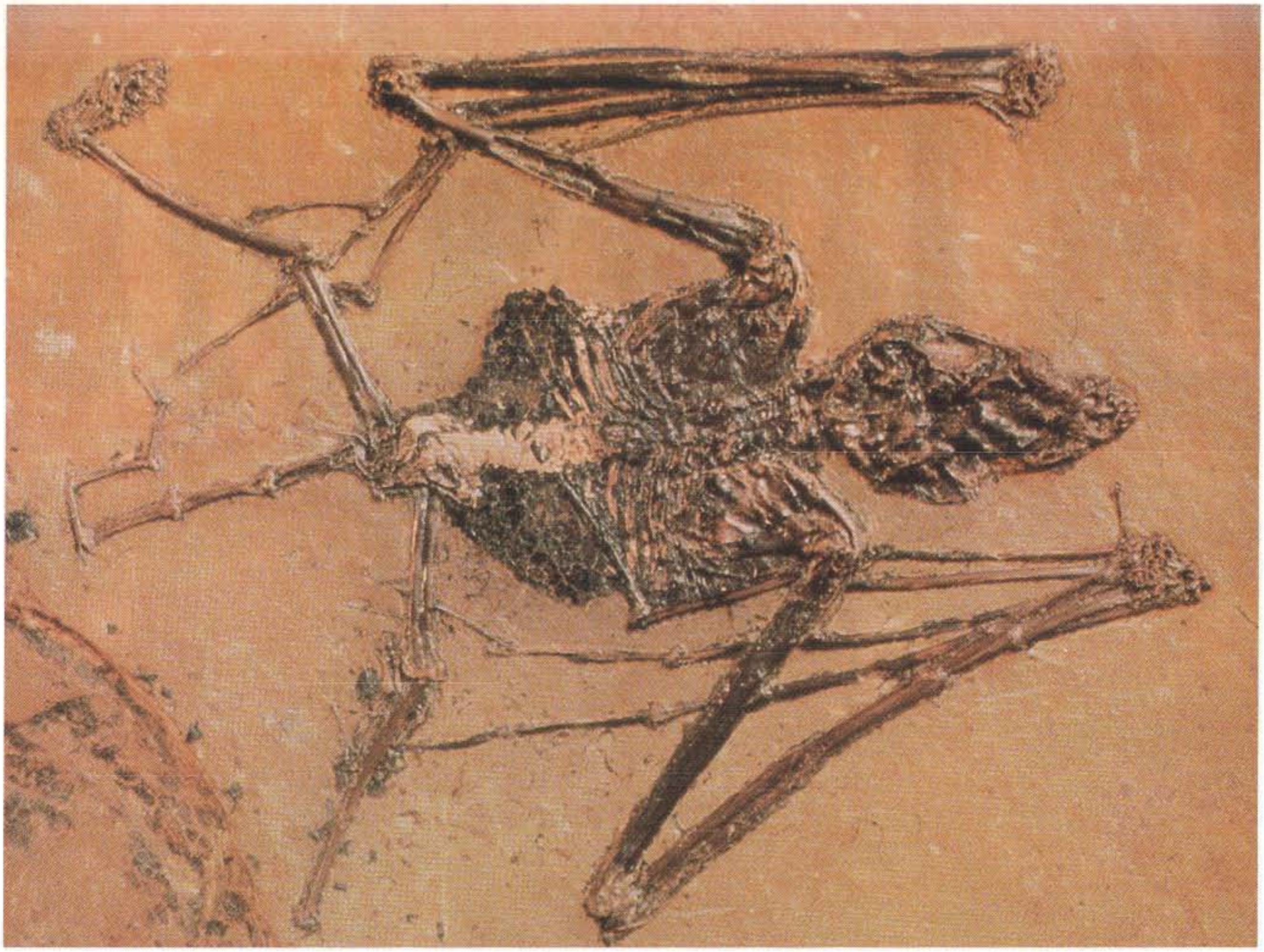
But there is diverse—although indirect—evidence of an African origin for a large number of extremely important taxa, indicating that these mammals went first to Europe and thence to North America. I believe, therefore, that in most cases immigrants of the early Eocene went west, not east—from Europe to the New World.

The fossil record in Africa is insufficient for the earlier periods, however, and so one must infer African beginnings mostly from evidence outside that continent. One can, for example, deduce an African homeland for any population that lacks a contemporaneous or earlier Asian correlate and that has obviously reached Europe before North America. Examples of such European precedence include *Hyracotherium* (the oldest known genus of horses), *Diacodexis* (the oldest known genus of artiodactyls, which include pigs, cattle and goats) and the lemurlike prosimians, the first primates of modern aspect. Moreover, within Europe these immigrants seem to have turned up earlier in the south than in the north. This is precisely what one would expect if Africa were the homeland.

Until discoveries in southern Europe of the progenitor of the horse, most workers had assumed that it, like the modern horse (*Equus*), had evolved in North America. Now European sites show that this was not the case. Further, Messel fossils led workers to suggest an African origin for the modern primates. That prediction found confirmation last year in the discovery of a Paleocene fossil primate in the Atlas Mountains of Morocco.

Perhaps no other specimen is as interesting for its own sake and for what it reveals of ancient migrations as the fossil anteater ***Eurotamandua joresi***, excavated at Messel in 1974. It is the oldest and best preserved of its suborder, the Vermilingua, in the order Edentata, which also includes the sloths and armadillos. Be-





BAT TRAP: fossil bats are normally rare, but at Messel they outnumber other mammals, probably because they were often caught above the Messel lake when it released gases. The gut of *Palaeochiropteryx tupaiodon* (*above*) held moths that flew at twilight or at night, proving that bats used echolocation 50 million years ago. A ground-dwelling insectivore, *Macrocranion tupaiodon* (*opposite page, top*), also hunted in the dark, as evidenced by its well-developed ears and nose and its tiny eyes. *Masillamys beegeri* (*middle*) was a rodent. An opossumlike marsupial (*bottom*) is as yet unclassified.

cause no fossil remains from this order have been found in the appropriate geologic sediments in North America, these animals almost certainly could not have made their way from South America via North America.

Africa, therefore, has been postulated as their path to Europe. Evidence supporting this view includes the narrowness of the proto-Atlantic channel in the late Cretaceous and early Tertiary: intermittent land connections formed between South America and Africa up to the late Cretaceous and perhaps even in the early Paleocene. Also, many ridges of the Atlantic's spreading seafloor remained above water, creating a series of stepping-stones as late as the Eocene-Oligocene transition, about 35 million years ago.

But I give serious consideration to another interpretation. Although the *Eurotamandua* from Messel lived 50 million years ago, it already had all the highly complex and diagnostic characters of the extant genera *Tamandua* (lesser anteaters) and *Myrmecophaga* (giant anteaters). The fossil specimen thus suggests an origin for the anteaters well back in the Cretaceous.

Besides, the primitive features preserved in living edentates have led most paleontologists and zoologists to regard them as the most primitive group of living placental mammals. They could well have been in existence before the southern supercontinent West-gondwana broke up into Africa and South America some 90 million years ago. This view of evolutionary history would predict that edentates occupied Africa a very long time ago, even though no living or fossil member of the order has ever been discovered there.

Further study will surely refine these hypotheses and, perhaps, produce better means of testing them. There is reason to hope that emerging techniques for recovering and analyzing ancient organic materials may find fertile ground in the wonderfully preserved fossils of Messel. If this happens, we shall gain priceless clues to the early ancestry of our mammal cousins and of ourselves.

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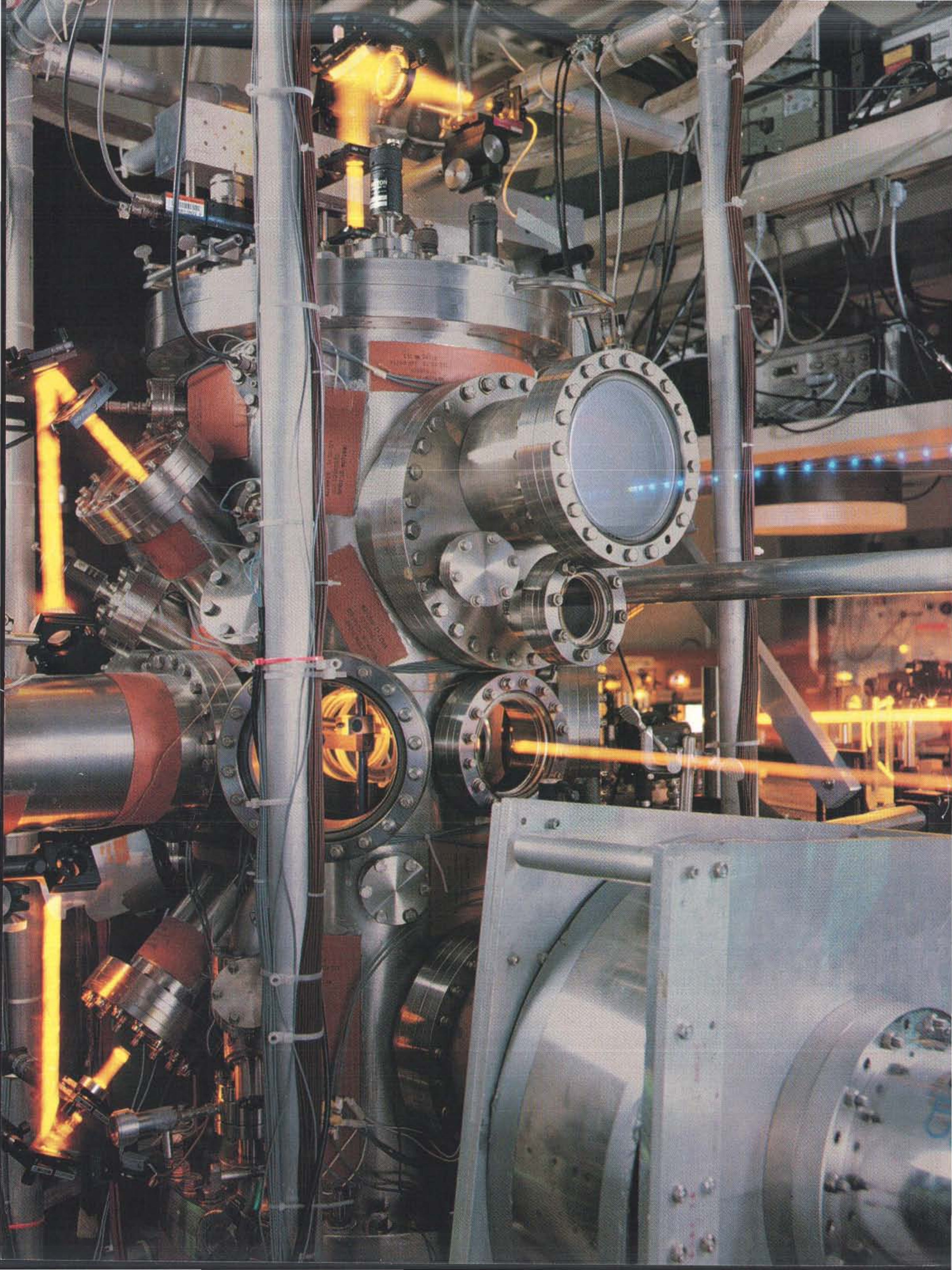

Laser Trapping of Neutral Particles

Lasers can be used to trap and manipulate electrically neutral particles. These techniques have allowed scientists to cool vapors to near absolute zero, develop new atomic clocks and stretch single molecules of DNA

by Steven Chu

Before you turn another page of this magazine, consider your actions carefully. Every time you wish to grasp a page, you must place one finger above the paper and another below so that the distance between each finger and the paper is about equal to the diameter of an atom. At that point, the electrons at the surface of your fingers repel the electrons on either side of the page. This slight redistribution of charges produces an electric field that is strong enough to allow you to squeeze the page between your fingers. Remarkably, by applying electric forces at the atomic scale, you can hold onto objects that are, on the whole, electrically neutral.

In contrast, manipulating neutral objects that are atomic in size is a formidable technical challenge. Charged objects are much easier to control because electric and magnetic fields can exert much stronger forces over them. Indeed, for more than a century, scientists have applied electromagnetic forces to manipulate charged particles such as electrons and ions from a distance. But only in the past few years have researchers been able to move neutral particles at a distance with any facility.

In particular, investigators have developed instruments that use lasers to trap and manipulate atoms and micron-size particles with astonishing control. These innovations have quickly led to a wide range of applications. My research group and others have cooled atoms to temperatures near absolute zero—conditions that allow us to examine quantum states of matter and unusual interactions between light and ultra-cold atoms. We have begun to develop atomic clocks and extremely sensitive accelerometers. Our techniques are being applied to handle such individual molecules as large polymers. In addition, we have devised an "optical tweezers" that uses laser beams to hold and move organelles inside of cells without puncturing the intervening membranes.

LASER BEAMS shine into a vacuum chamber that houses a fountain of atoms. The beams are used to trap and cool the atoms near the bottom of the apparatus. Once confined, the atoms are pushed upward, stopping near the top of the apparatus because of the pull of gravity. At that point, precise measurements can be made of the energy states of the atoms. The blue dots of light represent pulses of ultraviolet radiation that probe the atoms.

Almost a decade before scientists learned how to control neutral particles at a distance with laser light, they achieved some of the same tasks using magnetic fields. They applied fields to focus atoms in beams and trap them. After learning how to trap atoms with laser light, they turned to the vast arsenal of laser techniques to gain precise control over neutral particles.

The first trap for neutral particles was developed by Wolfgang Paul of the University of Bonn. In 1978 he and his colleagues succeeded in trapping neutrons in a magnetic field. Seven years later, using the same basic principles, William D. Phillips and his colleagues at the National Bureau of Standards were able to trap atoms.

The magnetic trap can hold onto particles that have magnetic properties similar to those of a tiny bar magnet. To be more precise, the particle must carry a small magnetic dipole moment. If such a particle is placed in a magnetic field whose strength varies from region to region, it will move toward the weakest or strongest part of the field, depending on the particle's orientation [*see illustration on next page*]. Paul realized that it is possible to design a magnetic field with a local minimum in the field strength, and if the magnetic dipole is originally aligned to seek a position where the field is weakest, it will remain aligned in the "weak field-seeking" orientation [see "Cooling and Trapping Atoms," by W. D. Phillips and H. J. Metcalf; SCIENTIFIC AMERICAN, March 1987].

Atoms can also be trapped by laser light. Light can exert forces on atoms and other neutral particles because it carries momentum. If an atom is bombarded with a beam of light of a particular frequency, it will continuously absorb and reemit photons, the quanta of light. As the atom absorbs photons, it will receive a barrage of momentum kicks in the direction that the light beam propagates. The kicks add up to produce a "scattering" force, which is proportional to the momentum of each photon and the number of photons that the atom scatters per second. Of course, for every photon the atom absorbs, it must emit one. But because the photons are released with no preferred direction, the changes in momentum caused by the emission average to zero. Absorption and emission have the net effect of pushing the atom in the direction that the light travels.

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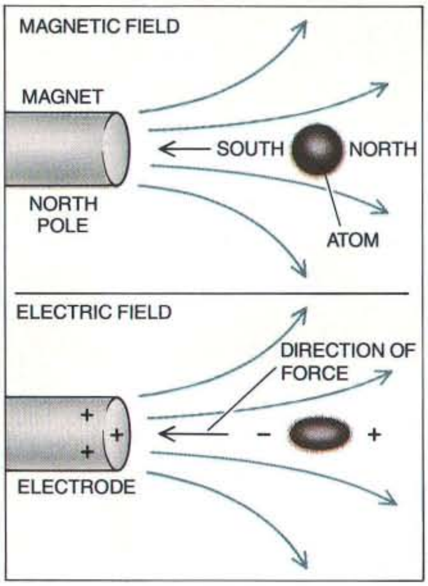


MAGNETIC AND ELECTRIC FIELDS can exert forces on atoms even though atoms are only slightly magnetic and electrically neutral. An atom in a magnetic field will be drawn toward the region of strongest field if the south pole of the atom points toward the north pole of the field. An atom in an electric field will be attracted toward the region of highest field as well. The electric field pulls on the negative charges in the atom, while repelling the positive charges. As a result of the new distribution of charge, the atom is attracted toward the positively charged rod.

The magnitude of this scattering force is quite low. If an atom absorbs a single photon, its change in velocity is tiny compared with the average velocity of atoms in a gas at room temperature. (The change is on the order of one centimeter per second, the crawling speed of an ant, whereas an atom at room temperature moves at the speed of a supersonic jet.)

This scattering force was first detected in 1933, when Otto R. Frisch used it to deflect a beam of sodium atoms. He prepared the atoms by vaporizing sodium in a container. To form the beam, he allowed the atoms to pass through a hole in the container and a series of slits. Once established, the beam was bombarded with light from a sodium lamp. Although, on average, each sodium atom absorbed only a single photon, Frisch was able to detect a slight deflection of the beam.

The scattering force that Frisch generated was far too weak to capture atoms. Decades later workers realized that the photon-scattering rate could be increased to more than 10 million photons per second, corresponding to a force 100,000 times greater than the pull of gravity by the earth. The first dramatic demonstration of the scattering force on atoms was made by two separate groups led by Phillips and John L. Hall at the National Bureau of Standards. In 1985 they stopped a beam of atoms and reduced the temperature of the atoms from roughly 300 kelvins (room temperature) to 0.1 kelvin.

The power of the scattering force attainable with lasers gave researchers hope that they could not only stop atoms but trap them as well. But attempts to configure several laser beams so that they could collect and concentrate atoms in some region of space seemed doomed to failure. According to a principle known as the Optical Earnshaw Theorem, it is impossible to fashion a light trap out of any configuration of light beams if the scattering force is proportional to the light intensity. The problem is that the beams cannot be arranged to generate only inward directed forces. Any light that enters a trapping region must eventually escape and must therefore carry outward directed forces as well. Even if Luke Skywalker were a physicist, the (scattering) force would not always be with him.

Fortunately, an atomic trap can be based on another kind of force that light can exert on atoms. To understand this force, it is instructive to consider how small particles can be attracted to a positively charged object, such as a glass rod rubbed with cat's fur. The rod produces an electric field that polarizes the particle. Consequently, the average position of positive charges in the particle will be slightly farther away from the rod than the average position of the negative charges. This asymmetric distribution of charge is said to have a dipole moment. The attractive dipole force exerted by the electric field on the negative charges of the particle is stronger than the repulsive force on the positive charges. As a result, the particle is pulled toward the regions where the electric field is strongest. Notice that this force is analogous to the magnetic dipole force first used to trap neutrons and atoms. If the charge on the rod were negative, the electric field would induce a dipole moment of reversed polarity, and the particle would still be attracted to regions of high electric field.

Because of the dipole force, atoms can be trapped by an electric field that has a local maximum of some point in space. Could such fields be produced by some clever arrangement of electric charges? For any system of fixed charges, the answer is no. Yet an electric field with a local maximum can be achieved in a dynamic system. In particular, because light is made up of rapidly oscillating electric and magnetic fields, a focused laser beam can produce an alternating electric field with a local maximum. When the field interacts with an atom, it alters the distribution of electrons around the atom, thereby inducing an electric dipole moment. The atom will thus be attracted to the local maximum in the field, just as the charged particle was drawn toward the rod.

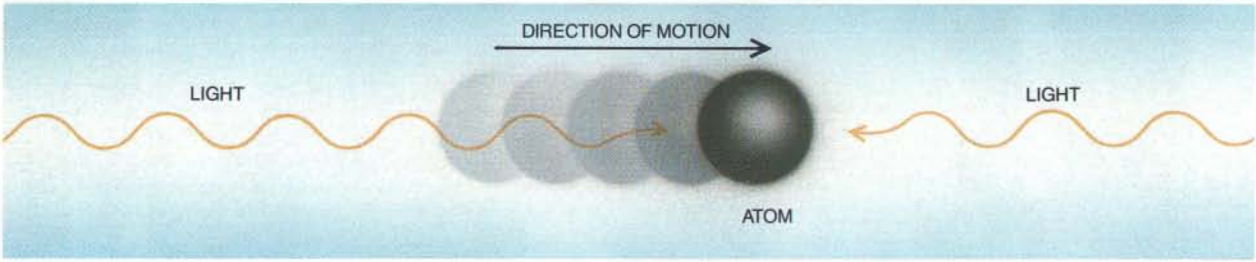
The fact that the electric field changes rapidly does not present a problem. As the field changes polarity, the dipole moment of the atom also switches around. As long as the field changes at a rate slower than the natural oscillation frequencies of the atom, the dipole moment remains aligned with the field. The atom therefore continues to move toward the local maximum. As a result, this dipole force can be used to confine atoms. In 1968 Vladilen S. Letokhov first proposed that atoms could be trapped in a light beam using the dipole force, and 10 years later Arthur Ashkin of AT&T Bell Laboratories suggested a more practical trap based on focused laser beams.

Although the dipole-force trap is elegant in conception, it had practical problems. To minimize the scattering force, the light must be tuned well below the frequency at which the atoms readily absorb photons. At those large detunings, the trapping forces are so feeble that atoms as cold as 0.01 kelvin cannot be held in the trap. Even when colder atoms were placed in the trap, they would boil out of the trap in a matter of a few thousandths of a second as a result of the ever present photon scattering. In addition, the task of injecting atoms into the trap seemed daunting because the volume of the trap would only be 0.001 cubic millimeter.

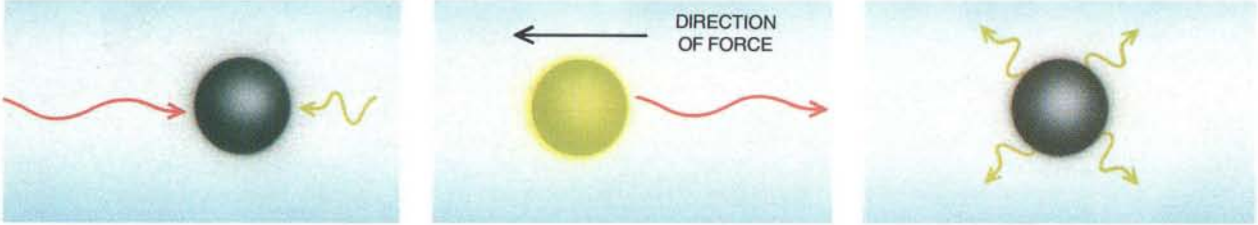
For these reasons, the challenges to optical trapping seemed formidable. Then, in 1985, a scheme for a workable optical trap became apparent after atoms were laser cooled in all dimensions and to much lower temperatures than the stopped atomic beams. The laser-cooling idea was first proposed in 1975 by Theodor Hänsch and Arthur Schawlow of Stanford University. In the same year, a similar scheme for cooling trapped ions with lasers was proposed by David J. Wineland and Hans G. Dehmelt of the University of Washington.

The researchers predicted that an atom could be cooled if it is irradiated from two sides by laser light at a frequency slightly lower than the frequency needed for maximum absorption. If the atom moves in a direction oppo-

How Light Can Slow Atoms Down



1. Consider two rays of light that bombard an atom. One ray travels in the same direction as the atom; the other moves in the opposite direction. The frequency of the light is slightly lower than the frequency that the atom readily absorbs.



2. From the atom's perspective, the ray moving in the same direction as the atom is shifted down in frequency; the other ray is shifted up in frequency.

3. The atom is likely to absorb the high-frequency light but not the low. It is therefore pushed in a direction opposite its motion and slows down.

4. The emission of the absorbed light pushes the atom in some direction, but if the process is repeated many times, the emission exerts no net force.

sing one of the light beams, the light, from the atom's perspective, increases in frequency. The light that has been shifted up in frequency is then likely to be absorbed by the atom. The light that the atom absorbs exerts a scattering force that slows the atom down.

How does the atom interact with the light traveling in the same direction? The atom is less likely to absorb the light because the light, again from the atom's perspective, has been shifted down in frequency. The net effect of both of the beams is that a scattering force is generated, opposing the motion of the atom. The beauty of this idea is that an atom moving in the opposite direction will also experience a scattering force dragging it toward zero velocity. By surrounding the atom with three sets of counterpropagating beams along three mutually perpendicular axes, the atom can be cooled in all three dimensions.

In 1985 Ashkin, Leo Hollberg, John E. Bjorkholm, Alex Cable and I at AT&T Bell Labs were able to cool sodium atoms to 240 millionths of a kelvin. Because the light field acts as a viscous force, we dubbed the combination of laser beams used to create the drag force "optical molasses." Although not a trap, the atoms were confined in the viscous medium for periods as long as 0.5 second, until eventually they would leak out of the cooling beams.

Optical molasses enabled us to solve the three major problems that stood in the way of constructing a laser trap. First, by cooling the atoms to extremely low temperatures, we could reduce the random thermal motions of the atoms, making them easy to trap. Second, we could easily load the atoms into the trap. Simply by focusing the trapping beam in the center of the optical molasses, atoms would be snagged as they randomly wandered into the trapping beam. Third, by alternating between trapping and cooling light, we could reduce the heating effects of the trapping light. A year after we had perfected optical molasses, atoms could finally be trapped with light.

Even with the loading technique used in our first trap, an optical trap with a larger capture volume was desirable. A trap that could use the scattering force would need much less light intensity, which meant the constraints imposed by the Optical Earnshaw Theorem had to be circumvented. The important clue of how to design such a trap came from David E. Pritchard of the Massachusetts Institute of Technology and Carl E. Wieman of the University of Colorado and their colleagues. They pointed out that if magnetic or electric fields that varied over space were applied to atoms, the scattering force caused by the laser light would not necessarily be proportional to the light intensity.

This suggestion led Jean Dalibard of the École Normale Supérieure in Paris to propose a "magneto-optic" trap, which used a weak magnetic field and circularly polarized light. In 1987 Pritchard's group and my own at AT&T collaborated to construct such a trap. Three years later Wieman's team went on to show that this technique could be used to trap atoms in a glass cell, using inexpensive diode lasers. Their method eliminated the precooling procedures needed in our first trapping experiments. The fact that atoms could be trapped in a sealed cell also meant rare species of atoms, such as radioactive isotopes, could be optically manipulated. The magneto-optic trap has become the most widely used optical trap today.

Meanwhile researchers were making rapid progress in laser cooling. Phillips and his colleagues discovered that under certain conditions, optical molasses could be used to cool atoms to temperatures far below the lower limit predicted by the existing theory. This discovery prompted Dalibard and Claude Cohen-Tannoudji of the Collège de France and the École Normale and my group at Stanford to construct a new theory of laser cooling based on a complex but beautiful interplay between the atoms and their interaction with the light fields. Currently atoms can be cooled to a temperature with an average velocity equal to three and a half photon recoils. For cesium atoms, it means a temperature lower than three microkelvins.

Going beyond optical molasses, Cohen-Tannoudji, Alain Aspect, Ennio Arimondo, Robin Kaiser and Nathalie Vansteenkiste, then all at the École Normale, invented an ingenious scheme capable of cooling helium atoms below the recoil velocity of a single scattered photon. Helium atoms have been cooled to two microkelvins along one dimension, and work is under way to extend this technique to two and three dimensions.

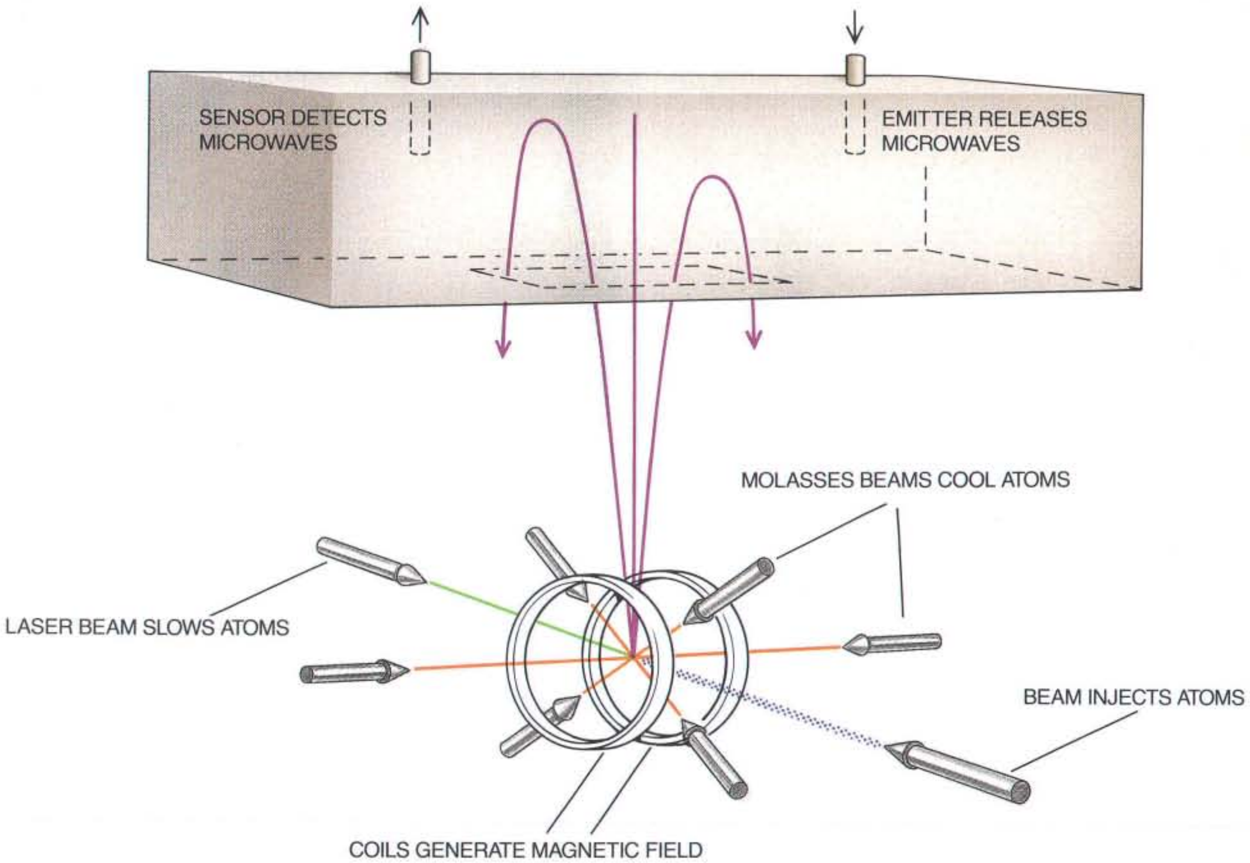
This cooling method captures an atom in a well-defined velocity state in much the same way atoms were trapped in space in our first optical trap. As the atom scatters photons, its velocity randomly changes. The French experiment establishes conditions that allow an atom to recoil and land in a particular quantum state, which is a combination of two states with two distinct velocities close to zero. Once in this state, the chance of scattering more photons is greatly reduced, meaning that additional photons cannot scatter and increase the velocity. If the atom does not happen to land in this quantum state, it continues to scatter photons and has more opportunities to seek out the desired low-velocity state. Thus, the atoms are cooled by letting them randomly walk into a "velocity trapped" quantum state.

Besides the cooling and trapping of atoms, investigators have demonstrated various atomic lenses, mirrors and diffraction gratings for manipulating atoms. They have also fashioned devices that have no counterpart in light optics. Researchers at Stanford and the University of Bonn have made "atomic funnels" that transform a collection of hot atoms into a well-controlled stream of cold atoms. The Stanford group has also made an "atomic trampoline" in which atoms bounce off a sheet of light extending out from a glass surface. With a curved glass surface, an atom trap based on gravity and light can be made.

Clearly, we have learned to push atoms around with amazing facility, but what do all these tricks enable us to do?

With very cold atoms in vapor form, physicists are in a position to study how the atoms interact with one another at extremely low temperatures. According to quantum theory, an atom behaves like a wave whose length is equal to Planck's constant divided by the particle's momentum. As the atom is cooled, its momentum decreases, thereby increasing its wavelength. At sufficiently low temperatures, the average wavelength becomes comparable to the average distance between the atoms. At these low temperatures and high densities, quantum theory says that a significant fraction of all the atoms will condense into a single quantum ground state. This unusual form of matter, called a Bose-Einstein condensation, has been predicted but never observed in a vapor of atoms. Thomas J. Greytak and Daniel Kleppner of M.I.T. and Jook T. M. Walraven of the University of Amsterdam are trying to achieve such a condensation with a collection of hydrogen atoms in a magnetic trap. Meanwhile other groups are attempting the same feat in a laser-cooled sample of alkali atoms such as cesium or lithium.

Atom-manipulation techniques are also offering new opportunities in high-resolution spectroscopy. By combining several such techniques, the Stanford group has created a device that will allow the spectral features of atoms to be measured with exquisite accuracy. We have devised an atomic fountain that launches ultra-cold atoms upward

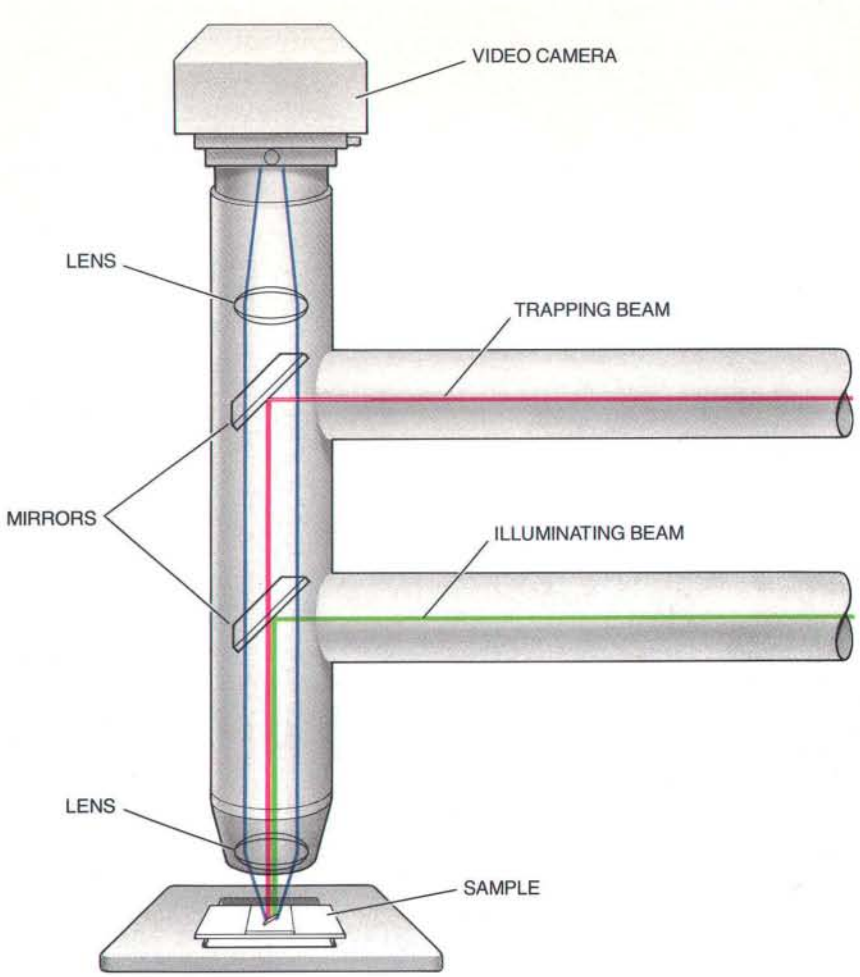

SENSOR DETECTS MICROWAVES
EMITTER RELEASES MICROWAVES
MOLASSES BEAMS COOL ATOMS
LASER BEAM SLOWS ATOMS
BEAM INJECTS ATOMS
COILS GENERATE MAGNETIC FIELD

ATOMIC FOUNTAIN allows precise measurements of the energy states of atoms. Atoms are injected into the apparatus and slowed by a laser beam. The atoms are then captured and cooled by the combined effects of a magnetic field and several light beams. After about 10 million atoms have accumulated in the trap, the atoms are launched upward. At the top of the trajectory, microwave pulses excite the atom from one energy state to another.

gently enough to have gravity turn them around. Atoms for the fountain are collected by a magneto-optic trap for 0.5 second. After that amount of time, about 10 million atoms are launched upward at a velocity of roughly two meters per second. At the top of the trajectory, an atom is probed with two pulses of microwave radiation separated in time. If the frequency of the radiation is properly tuned, the two pulses cause the atom to change from one quantum state to another. (Norman Ramsey shared the Nobel Prize in Physics in 1989 for inventing and applying this technique.) In our first experiment we measured the energy difference between two states of an atom with a resolution of two parts in 100 billion.

How does the fountain make such precise measurements possible? First, the atoms fall freely and are easy to shield from any perturbation that might alter their energy levels. Second, such measurements are limited in precision by the Heisenberg uncertainty principle. This principle states that the resolution of an energy measurement will be limited to Planck's constant divided by the time of the "measurement." In our case, this time corresponds to the time between the two microwave pulses. With an atomic fountain the measurement time for unperturbed atoms can be as long as one second, a period impossible with atoms at room temperature.

Because the atomic fountain allows extremely precise measurements of the energy levels of atoms, it may be possible to adapt the device to make an improved atomic clock. At present, the world time standard is defined by the energy difference between two particular energy levels in ground states of the cesium atom. Two years after the first atomic fountain, the group at the École Normale used a fountain to measure the "clock transition" in the cesium atom with high precision. These two experiments suggested that a properly engineered instrument might be able to measure the absolute frequency of this transition to one part in 10^{16}, 1,000 times better than the accuracy of our best clocks. Lured by this potential, more than eight groups around the world are now trying to improve the cesium time standard with an atomic fountain.



OPTICAL TWEEZERS can manipulate microscopic objects such as cells. A sample is placed on the stage of a microscope, which has been adapted to admit green laser light and infrared laser radiation. The green light illuminates the sample while the infrared radiation traps and holds it.

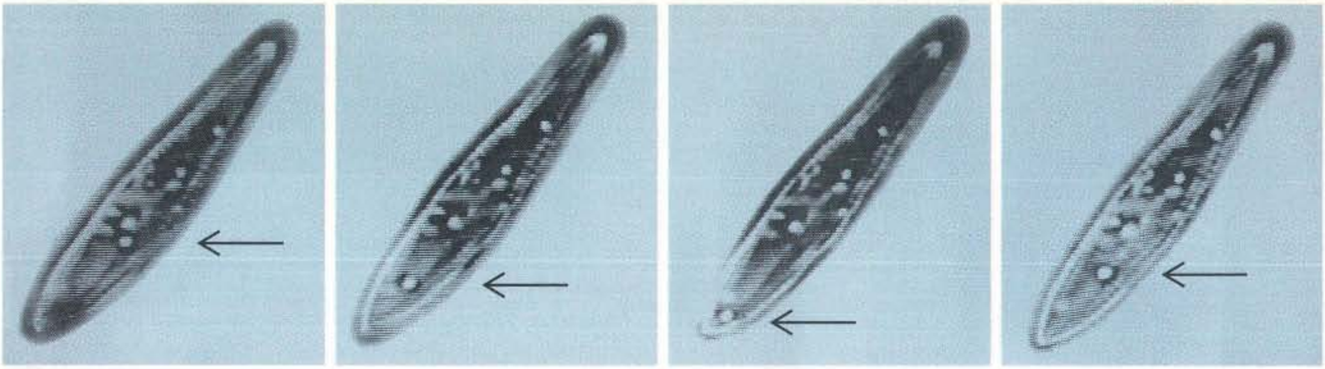
Another application being intensively studied is atom interferometry. The first atom interferometers were built in 1991 by investigators at the University of Konstanz, M.I.T., the Physikalisch-Technische Bundesanstalt and Stanford.

An atom interferometer splits an atom into two waves separated in space. The two parts of the atom are then recombined and allowed to interfere with each other. The simplest example of such a splitting occurs when the atom is made to go through two separated mechanical slits. If the atom is recombined after passing through the slits, wavelike interference fringes can be observed. The interference effects from atoms dramatically demonstrate the fact that their behavior needs both a wave and a particle description.

More important, atom interferometers offer the possibility of measuring physical phenomena with high sensitivity. In the first demonstration of the potential sensitivity, Mark Kasevich and I have created an interferometer that uses slow atoms. The atoms were split apart and recombined in a fountain. With this instrument we have already shown that the acceleration of gravity can be measured with a resolution of at least three parts in 100 million, and we expect another 100-fold improvement shortly. Previously, the effects of gravity on an atom have been measured at a level of roughly one part in 100.

In recent years the work on atom trapping has stimulated renewed interest in manipulating other neutral particles. The basic principles of atom trapping can be applied to micron-size particles, such as polystyrene spheres. The intense electric field at the center of a focused laser beam polarizes the particle, just as it would polarize an atom. The particle, like an atom, will also absorb light of certain frequencies. Glass, for example, strongly absorbs ultraviolet radiation. But as long as the light is tuned below absorption frequency, the particle will be drawn into the region of highest laser intensity.

In 1986 Ashkin, Bjorkholm, J. B. Dziedzic and I showed that particles that range in size between 0.02 and 10 microns can be trapped in a single focused laser beam. In 1970 Ashkin trapped micron-size latex spheres suspended in water in between two fo-



ORGANELLE inside a protozoan was dragged to one end of the cell using an optical tweezers, as shown in the first three photographs. The image seen at the far right shows the organelle after it was released.

cused, counterpropagating beams of light [see "The Pressure of Laser Light," by Arthur Ashkin; SCIENTIFIC AMERICAN, February 1972]. But only much later was it realized that if a single beam is focused tightly enough, the dipole force would suffice to overcome the scattering force that pushes the particle in the direction that the laser beam is traveling.

The great advantage of using a single beam is that it can be used as an optical tweezers to manipulate small particles. The optical tweezers can easily be integrated with a conventional microscope by introducing the laser light into the body of the scope and focusing it with the viewing objective. A sample placed on an ordinary microscope slide can be viewed and manipulated at the same time by moving the focused laser beam.

One application of the optical tweezers, discovered by Dziedzic and Ashkin, has captured the imagination of biologists. They found that the tweezers can handle live bacteria and other organisms without apparent damage. The ability to trap live organisms without harm is surprising, considering that the typical laser intensity at the focal point of the optical tweezers is about 10 million watts per square centimeter. It turns out that as long as the organism is very nearly transparent at the frequency of the trapping light, it can be cooled effectively by the surrounding water. To be sure, if the laser intensity is too high, the creature can be "optocuted."

Many applications have been found for the optical tweezers. Ashkin showed that objects within a living cell can be manipulated without puncturing the cell wall. Steven M. Block and his colleagues at the Rowland Institute in Cambridge, Mass., and at Harvard University have studied the mechanical properties of bacterial flagella. Michael W. Berns and his co-workers at the University of California at Irvine have manipulated chromosomes inside a cell nucleus.

Optical tweezers can be used to examine even smaller biological systems. My colleagues Robert Simmons, Jeff Finer, James A. Spudich and I are applying the optical tweezers to study muscle contraction at the molecular level. Related studies are being carried out by Block and also by Michael P. Sheetz of Duke University. One of the goals of this work is to measure the force generated by a single myosin molecule pulling against an actin filament. We are probing this "molecular motor" by attaching a polystyrene sphere to an actin filament and using the optical tweezers to grab onto the bead. When the myosin head strokes against the actin filament, the motion is sensed by a photodiode at the viewing end of the microscope. A feedback circuit then directs the optical tweezers to pull against the myosin in order to counteract any motion. In this way, we have measured the strength of the myosin pull under tension.

On an even smaller scale, Spudich, Steve Kron, Elizabeth Sunderman, Steve Quake and I are manipulating a single DNA molecule by attaching polystyrene spheres to the ends of a strand of DNA and holding the spheres with two optical tweezers. We can observe the molecule as we pull on it by staining the DNA with dye molecules, illuminating the dye with green light from an argon laser and detecting the fluorescence with a sensitive video camera. In our first experiments we measured the elastic properties of DNA. The two ends were pulled apart until the molecule was stretched out straight to its full length, and then one of the ends was released. By studying how the molecule springs back, we can test basic theories of polymer physics far from the equilibrium state.

The tweezers can also be used to prepare a single molecule for other experiments. By impaling the beads onto the microscope slide and increasing the laser power, we found that the bead can be "spot-welded" to the slide, leaving the DNA in a stretched state. That technique might be useful in preparing long strands of DNA for examination with state-of-the-art microscopes. Ultimately, we hope to use these manipulation abilities to examine the motion of enzymes along the DNA and to address questions related to gene expression and repair.

It has only been six years since workers have stopped atoms, captured them in optical molasses and made the first atom traps. Optical traps, to paraphrase a popular advertising slogan, have enabled us to "reach out and touch" particles in powerful new ways. We have shown that if we can "see" an atom or microscopic particle, we may be able to hold onto it regardless of intervening membranes. It has been a personal joy to see how esoteric conjectures in atomic physics have blossomed: the techniques and applications of laser cooling and trapping have gone well beyond our dreams during those early days. We now have important new tools for physics, chemistry and biology.

FURTHER READING

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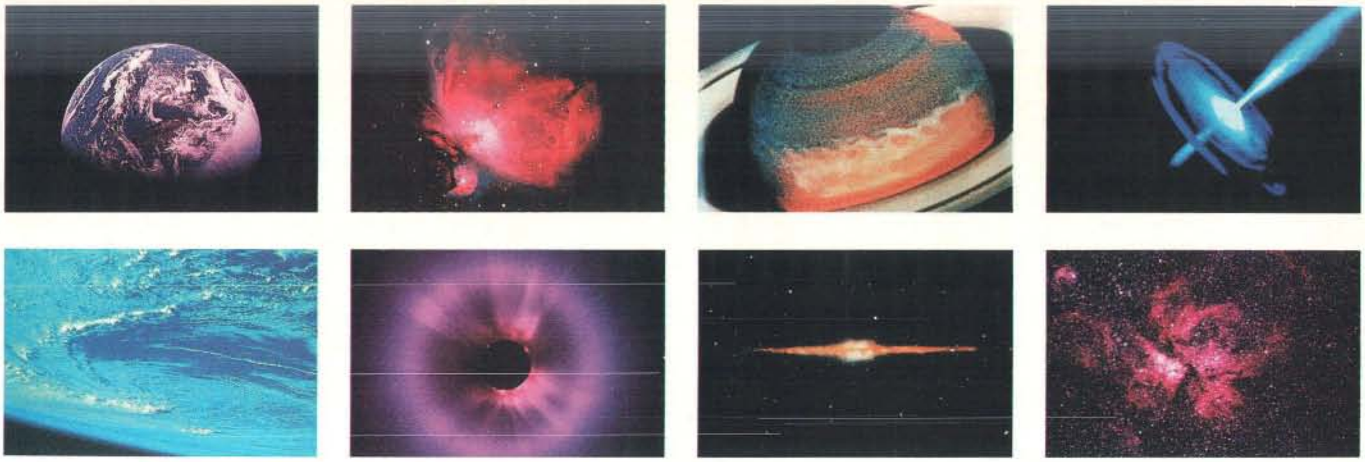

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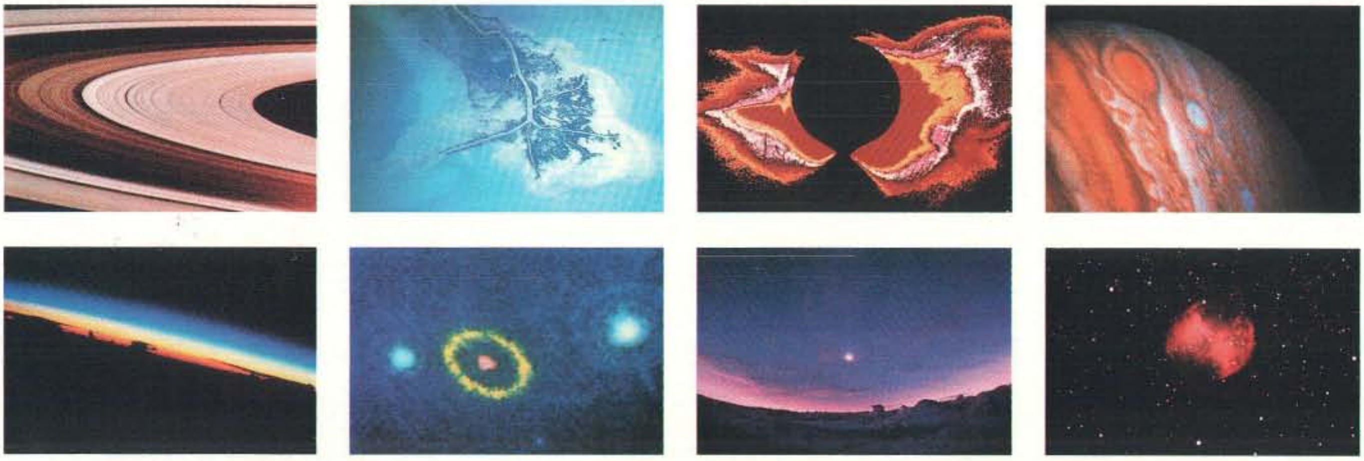

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This event combines for the first time the 43rd Congress of the International Astronautical Federation, the 35th International Colloquium on the Law of Outer Space, and the 29th Plenary Meeting of the Committee on Space Research, under the auspices of the National Aeronautics and Space Administration, the National Academy of Sciences, and organized and hosted by the American Institute of Aeronautics and Astronautics. The United Nations views the World Space Congress as a strong encouragement for international cooperation in space science and applications for the betterment of humanity.

Turquoise in Pre-Columbian America

Before the conquistadores arrived, this gem's religious and economic significance in Mesoamerica helped to create extensive trade and cultural exchanges with the American Southwest

by Garman Harbottle and Phil C. Weigand

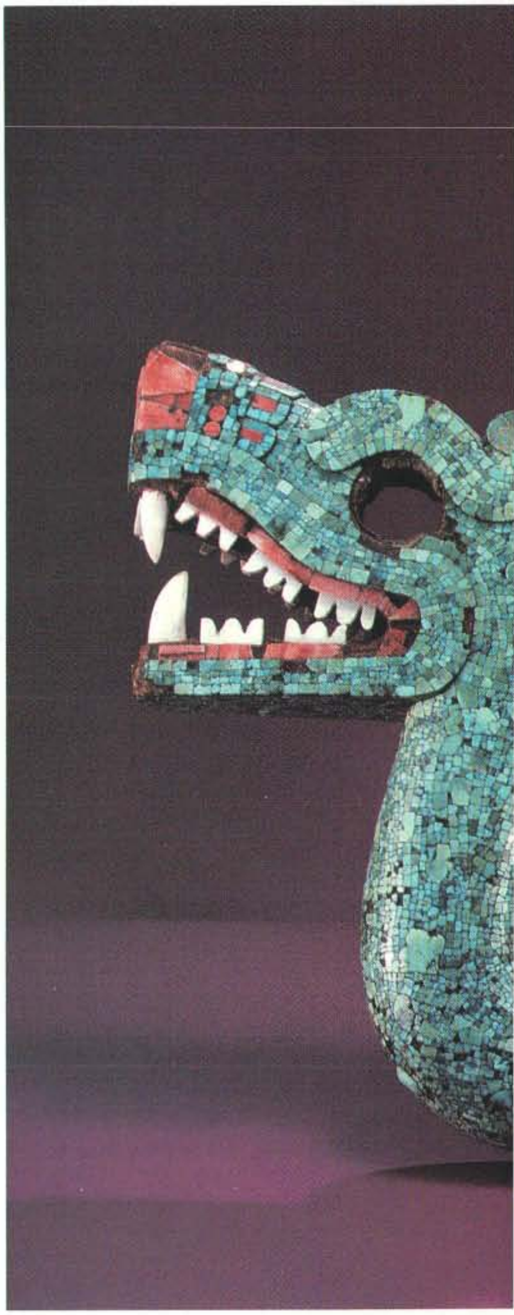
When Cortés landed in Mexico in 1519, Charles V ruled in Spain. The rich gifts presented to Cortés by the ambassadors of the Aztec emperor Montezuma II were not, however, intended to be the usual magnificent tokens of esteem of one emperor for another. Rather they were religious offerings of a devout nation to one of its gods. For Montezuma had become convinced that Cortés was in fact Quetzalcóatl, the feathered serpent god in human form, returned to Mexico from his mythical journey to distant lands. The Spanish chronicler Bernardino de Sahagún describes these gifts: "First was the array of Quetzalcóatl: a serpent mask made of turquoise; a quetzal feather headband and a mirror for the small of the back... like a turquoise shield, of turquoise mosaic—encrusted with turquoise, glued with turquoise." When the ambassadors found Cortés and went aboard his ship, "they bore in their arms the array of the gods... they adorned the Captain himself; they put on him the turquoise mosaic serpent mask; with it went the quetzal feather headband."

Turquoise in this pre-Columbian "Mesoamerican" society clearly was more than an extravagantly valuable possession. The gem was also a metaphor for life in social and religious realms. Words of wisdom were likened to precious turquoise, and the stone became a symbol of noble status. It even outstripped its competitor gem, jade, in consumption.

The abundance of worked turquoise in Mesoamerica has posed a problem for students of the region's culture. There are no turquoise mines in the immediate area. In fact, the only large deposits lie to the north, in the American Southwest and adjacent parts of northernmost Mexico. Virtually all the mines on the North American continent extend in a great arc from California to Colorado. Could the Mesoamericans have traded with the natives of the Southwest to obtain the stone they considered metaphorically as precious as water?

Conventional scholarship has long asserted that at best only casual connections existed between the two regions. But modern scientific examination and archaeological studies prove that a highly structured, formal trade system developed. Indeed, turquoise, which preserves well and was in great demand, provides some of the most crucial evidence for systematic contact. In addition, the channels of communication opened by the trade led to reciprocal cultural exchanges. Evidence shows that Mesoamerica strongly influenced the social development of the Southwest. Moreover, the indigenous people of the Southwest eventually came to regard turquoise as more than an export item.

GARMAN HARBOTTLE and PHIL C. WEIGAND have studied the artifactual use of turquoise for more than 20 years. Harbottle received his Ph.D. from Columbia University. A senior chemist at the Brookhaven National Laboratory, he applies nuclear science to the solution of archaeological problems. Weigand, an anthropologist, holds positions at the Colegio de Michoacán in Mexico and at the Museum of Northern Arizona in Flagstaff. He received his Ph.D. from Southern Illinois University and is currently directing archaeology projects in Mexico and the southwestern U.S.



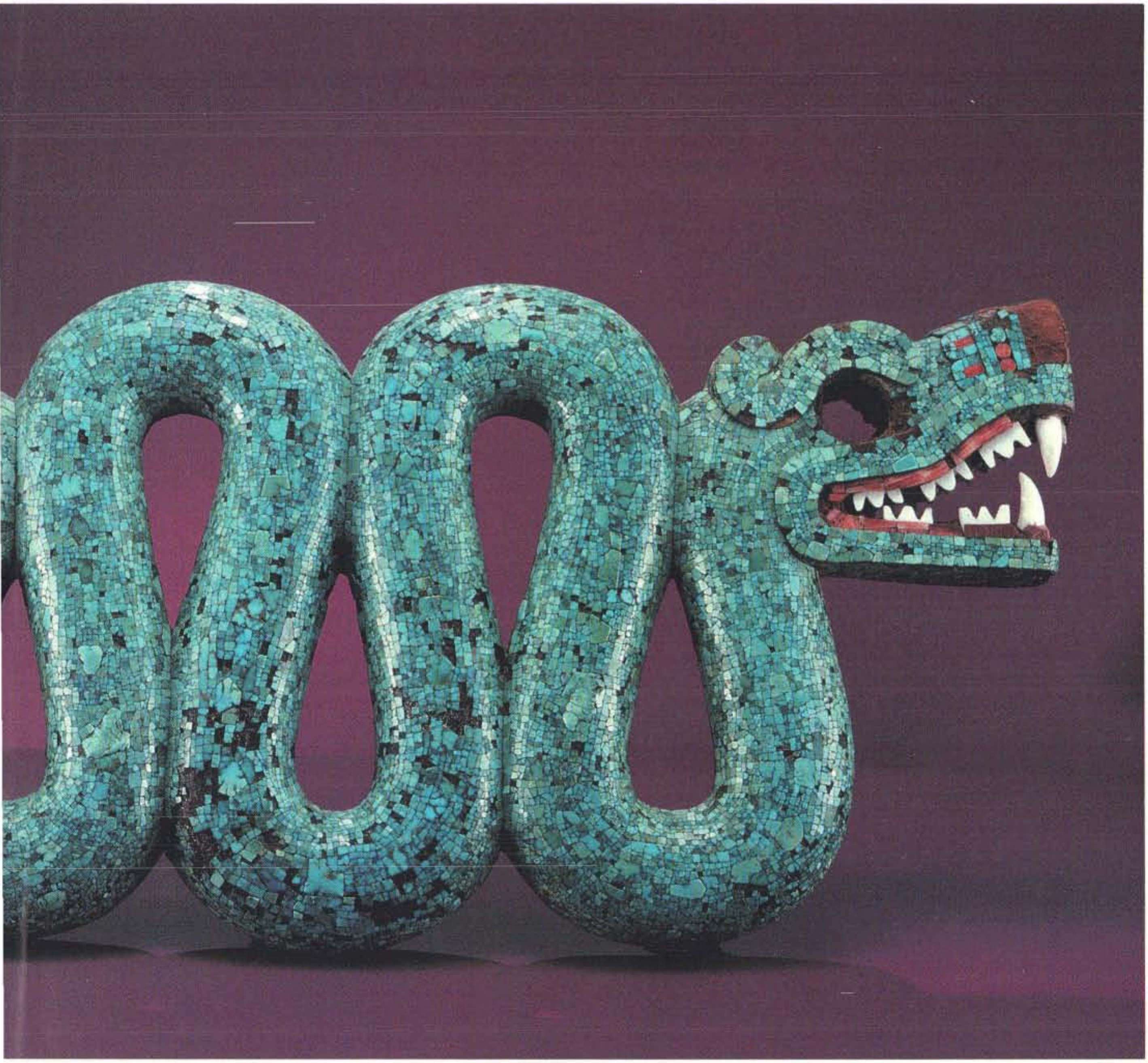
DOUBLE-HEADED SERPENT, now at the British Museum, is a 17-inch-long ornamental pendant that consists of wood inlaid with turquoise. The red facial features and the white teeth of this Aztec piece are made of shell.

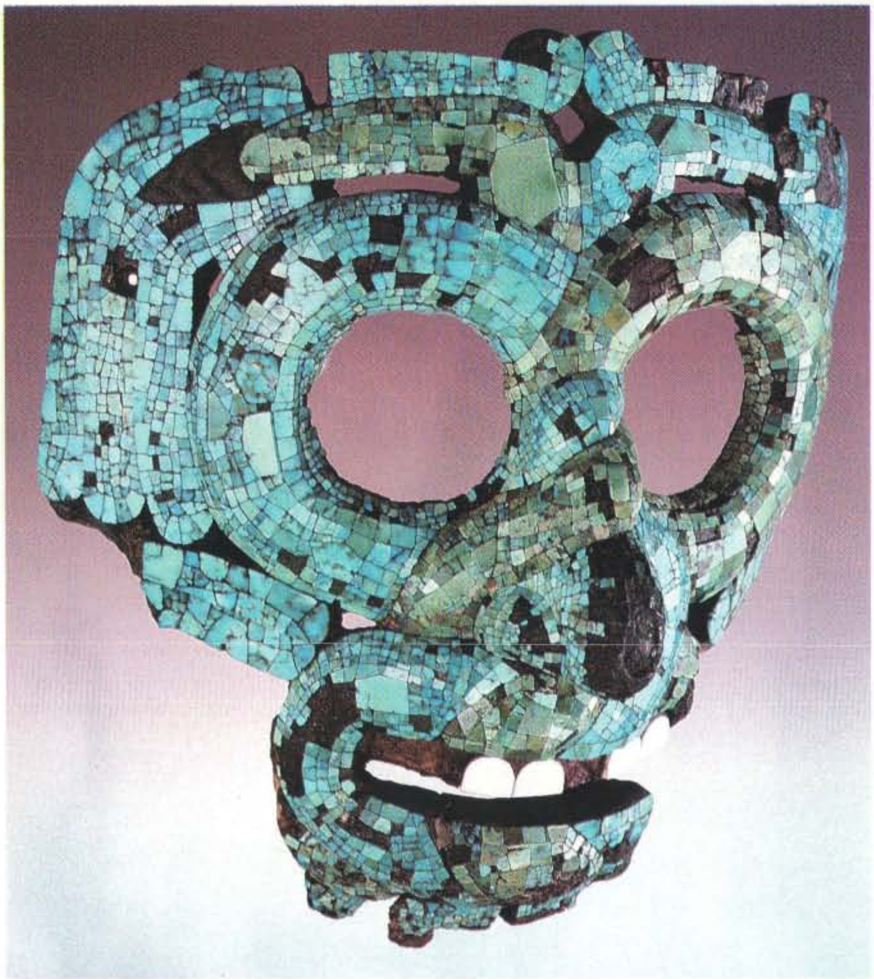
They began to suffuse it with theocratic meaning, as did the Mesoamericans.

To prove that turquoise was formally traded, one would have to show that the stone mined in one region is the same as that used in another. More than a million pieces of turquoise have been archaeologically recovered throughout the Southwest and Mesoamerica. Chemical analysis enables investigators to discover whether one such specimen is related to another, even if the objects are found at locations separated by great distances or belong to different periods.

The fingerprinting technique is called neutron-activation analysis. To implement this nondestructive method, we bombard a sample with a beam of neutrons, creating various radioisotopes of such major and trace elements as sodium, potassium, barium, scandium, several rare-earth elements, manganese, iron, cobalt, arsenic and copper; the last gives turquoise its color. Turquoise mines can, in general, be identified by certain definite quantities of these elements. Thus, a similar compositional pattern indicates a common origin. We have used neutron activation during the past two decades to analyze more than 2,000 pieces found at 28 archaeological sites in Mesoamerica and the Southwest and collected at more than 40 turquoise mining areas in the Southwest. Typically we analyzed 10 to 40 samples of turquoise from each mine. From each of several major archaeological sites, we examined nearly 100 artifacts. This approach has enabled us to trace, for example, several dozen pieces found in Mexico to specific mines more than 1,000 miles away, in New Mexico, Arizona and Nevada.

We have also tried to estimate the consumption of turquoise to determine how extensive and well established the trade had become. To do so, we used a variety of methods. The most direct involved counting, and often weighing, artifacts recovered through excavation or extant in museum or private collections. When the turquoise pieces had





SERPENT MASK of Quetzalcóatl, now at the British Museum, is very probably the mask presented on Montezuma's behalf to Cortés in 1519. The two coiled serpents on the face are made from different shades of turquoise that blend over the nose.

never been fully catalogued, such as those from the early collections from Chaco Canyon, N.M., we estimated the amount. We measured the space in the museum containers that hold the artifacts and then counted out a control number within a known volume. Simple multiplication provides an estimate. In other circumstances, we examined illustrations of turquoise artifacts in catalogues and art books and then counted the individual pieces. For mosaics, we added only the pieces we could see; hence, the estimates of tesserae, or mosaic pieces, are probably too low.

Such a mix of methods clearly means that our estimates are approximate. Future archaeological work may well require some modification of our numbers. Nevertheless, we believe our estimates to be informed and consistent with the present state of archaeological knowledge. When coupled with previous work, our studies enable us to piece together the history of turquoise use and discern the gradual development of the system of trade between Mesoamerica and the Southwest.

The earliest use of the gem dates to 600 B.C., near Mezcala, Guerrero, where Rosa Reina of the National Institute of Anthropology and History in Mexico found turquoise in burials. Very rare pieces from 300 B.C. have been recovered from shaft tombs near Teuchitlan in Jalisco. But Mesoamericans began to appreciate turquoise only when their complex cultures emerged. We believe the Chalchihuites area of Zacatecas, Mexico, was the first Mesoamerican region to use large amounts of turquoise, during the middle of what researchers call the Classic period of Mesoamerican culture (A.D. 100–900).

By A.D. 600 this northwestern Mesoamerican society was in full bloom, extensively mining nearby deposits of malachite, azurite, chert, cinnabar, hematite and possibly native copper. Evidence of extensive turquoise working appears at about A.D. 700. At that time, the inhabitants of the major ceremonial center there, called Alta Vista, began to import raw turquoise in large quantities. Our neutron-activation analysis leads us to conclude that the Cerrillos area of New Mexico was a major source.

Indeed, Alta Vista, recently explored by J. Charles Kelley of Southern Illinois University, has the greatest turquoise workshop yet documented in North America. Turquoise there was primarily for ceremonial purposes: prestige burials included rings, beads, pendants and disk mosaics. The edges of the tesserae were beveled. We saw how essential the beveled-edge technology was for mosaic stability and a smooth, finished appearance after we disassembled several fragments of a turquoise mosaic from Postclassic Oaxaca. The juncture between two adjacent beveled pieces almost disappears into a fine line. The tesserae were "glued" onto the wooden base by a charcoal-chia seed oil mixture called *chaute* applied to their backs. The dust beneath them was a highly processed, fine silica abrasive that we believe the artisans used for beveling, grinding and polishing the pieces.

In addition to finished objects, archaeologists have found a large amount of turquoise debris and raw chunks at Alta Vista. We found evidence for the existence of more unprocessed turquoise than was subsequently worked there. The excess was probably reserved for other products meant to be shipped elsewhere. We may surmise the destinations were the Classic period cities of central Mexico: Teotihuacán and Cholula. Although neither great city has produced much artifactual turquoise, their burials of high-status individuals—where one expects to find turquoise—have never been adequately explored.

The next period of well-documented use of turquoise occurred in the Mesoamerican Late Classic (circa A.D. 700–900) and the Early Postclassic (circa A.D. 900–1200). Indeed, turquoise became widespread throughout Mesoamerica. The people of the American Southwest, especially in and around Chaco Canyon, also began using turquoise during this period, but only in small amounts. The gem was still chiefly mined for export to Mesoamerica.

The extraordinary developments that took place during the Anasazi settlement of Chaco Canyon dating from the late Pueblo II period (circa A.D. 1050–1180) illuminate the effects that Mesoamerica and the American Southwest exerted on each other through the turquoise trade [see "The Chaco Canyon Community," by Stephen H. Lekson, Thomas C. Windes, John R. Stein and W. James Judge; SCIENTIFIC AMERICAN, July 1988]. From a modest beginning of hamlets spread across the Colorado Plateau, a highly differentiated, structured social system rapidly evolved at Chaco Canyon: the emergence of large aggregations of exotic buildings constructed according to novel architectural techniques suggests a well-organized political and economic structure. The architecture was not merely new to the Southwest; it also imported Mesoamerican building technology, such as the rubble core and veneer walls seen throughout the canyon and in the two platforms in front of Pueblo Bonito.

In addition, an extensive system of roads linked the Chaco settlement to outlying pueblos of similar construction. Favored access to rare resources—we shall demonstrate that turquoise was one of them—was almost certainly a major force in the site's spectacular societal development. These attributes together indicate a society that had a special role on the northern frontier of Mesoamerica.

Further evidence of the influence of Mesoamerica on the Southwest lies in the overall layout of the community. Mesoamerican cities were generally dispersed and not densely packed. In the Southwest, if one assumes that the different pueblo blocks within the canyon are wards of a single settlement rather than a series of egalitarian villages, one can make a case for the existence of an early city organized in a Mesoamerican fashion.

Several other considerations hint that Chaco Canyon was probably influenced by the Mesoamerican Early Postclassic culture. Evidence for such Mesoamerican high-status imports as macaws and copper bells has been unearthed in the canyon. Elaborate burials similar to those in Mesoamerica were found. Finally, the Southwest began a massive exploitation of turquoise, in much the same manner as Mesoamerica had sponsored three centuries before.

Indeed, Chaco Canyon contains some of the most substantial archaeological finds of turquoise ever made. Jonathan Reyman of Illinois State University estimated that 500,000 pieces have been recovered. W. James Judge, then at Southern Methodist University, derived a smaller number: about 200,000. No matter which figure is accurate, they are both impressive. The ceremonial use of turquoise during the peak period of cultural activity (circa A.D. 975–1130), in elaborate burials and great kivas (ceremonial structures), was unprecedented in the Southwest. The closest prior model of such use on a comparable scale is Alta Vista.

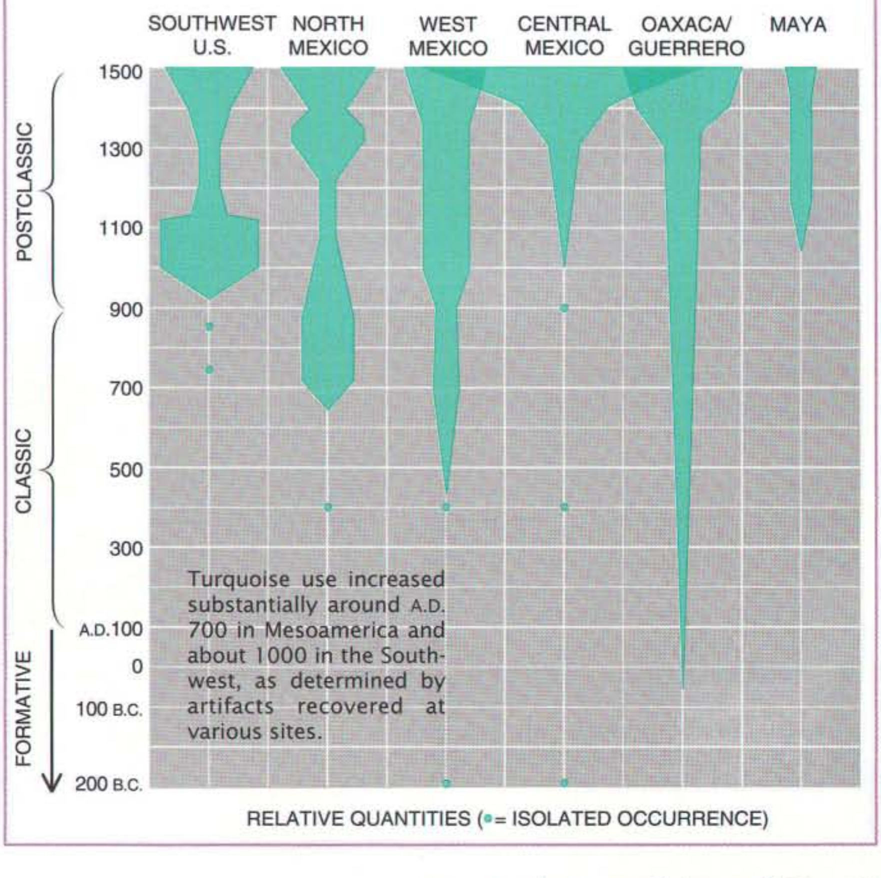
Much of this turquoise came from Cerrillos, but there were other sources as well. Many tesserae were beveled and made in standardized measures. Because beveling and tesserae standardization are Mesoamerican innovations (probably from Alta Vista), their presence in the American Southwest is another strong indicator of contacts.

In addition to performing extravagant ceremonies involving turquoise, the people of Chaco Canyon seemed to control the distribution of the stone. David H. Snow, then at the Museum of New Mexico, who was one of the pioneers of the study of turquoise use in the Southwest, detailed how the gem became concentrated at Chaco Canyon. He helped to show that the system of mineral procurement there operated in a near monopolistic fashion. In fact, our neutron-activation analyses have shown a direct link between Chaco Canyon turquoise and turquoise excavated from other sites in the Southwest (the Tucson basin and Snaketown, both in Arizona). Turquoise in Mesoamerica also very probably came directly from the canyon. Artifacts found at various sites in Mexico, including Guasave in Sinaloa, Las Cuevas and Zacoalco in Jalisco and the Ixtlán del Rio area in Nayarit, match Chaco Canyon turquoise mined from Cerrillos.

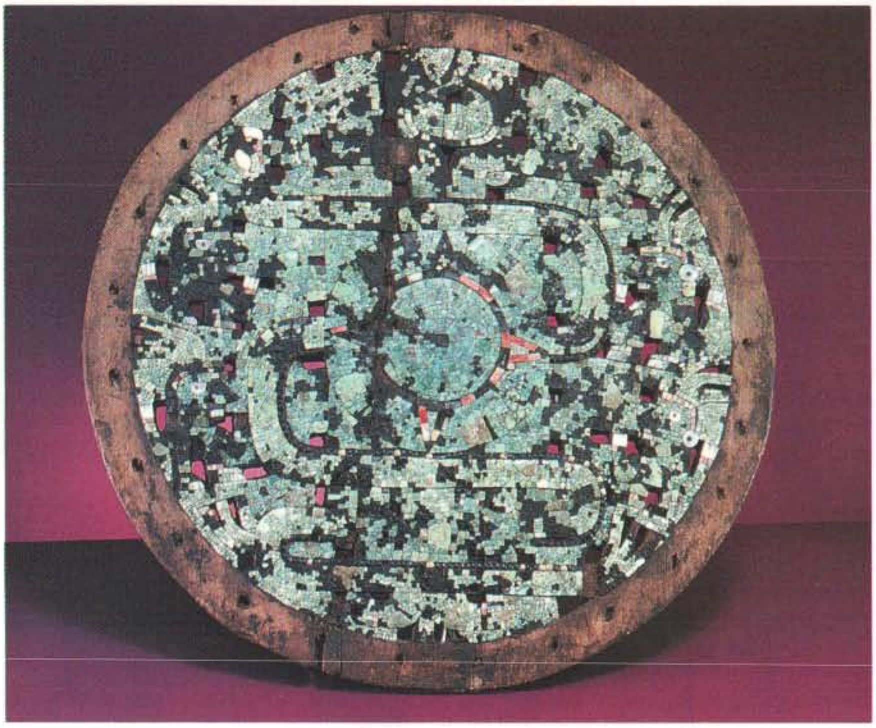
The skewed distribution of turquoise during Chaco Canyon's heyday correlates with another development. After adopting beveled-edge technology and tesserae standardization for micromosaic manufacture, the Southwest no longer traded the raw material in quantity to the consuming societies in the Mesoamerican heartlands. Instead the people of the Southwest finished the turquoise themselves. The procurement system and manufactory at Chaco Canyon is probably the first mark of the structural integration of the Southwest into the Mesoamerican trade system, a process that intensified with time.

Chaco Canyon seems to have lost its monopoly on turquoise sometime during the 12th century. In fact, the event may have contributed to the canyon's societal decline. Other sites, such as the Aztec ruin in New Mexico, came to dominate the Anasazi region by the late 12th century. As David R. Wilcox of the Museum of Northern Arizona has pointed out, no other center could quite take Chaco Canyon's place in the trading system, although the mechanism of turquoise procurement and exchange certainly survived. Indeed, turquoise consumption in Mesoamerica continued to increase during the 13th century.

The Popularity of Turquoise



Turquoise use increased substantially around A.D. 700 in Mesoamerica and about 1000 in the Southwest, as determined by artifacts recovered at various sites.



AZTEC SHIELD consists of turquoise tesserae glued on a 12-inch-diameter wood disk. From the 10 o'clock position, a serpent winds around the vertical axis. The holes along the edge were intended to hold feathers.

Concomitant with that increase in Mesoamerica was a shift in consumption in the Southwest. The gem, formerly the exclusive possession of the religious and ruling elites, found its way into jewelry worn by many of lower social status. Never again was turquoise used so exotically and extravagantly or distributed in such a highly differentiated way in so few sites. That pattern in the Southwest collapsed when Chaco Canyon's monopoly was broken.

Increasing demand in the Southwest created supply problems. To meet the needs of Mesoamerica and the region itself, additional sources had to be opened up during the mid-13th century. The first great period of turquoise mining had begun, perhaps not equaled again until the post-World War II rush on the resource. Charles C. Di Peso of the Amerind Foundation conducted research at the Mesoamerican urban center of Casas Grandes in Chihuahua, Mexico (just below the New Mexico border), and recovered turquoise from many new sources. These areas include the Mojave Desert and regions in southern Nevada, southwesternmost New Mexico, as well as the perdurable Cerrillos. Casas Grandes was one of several entrepôts procuring turquoise for the ever expanding Mesoamerican market. The opening of new mines has a parallel in the modern world: when the demand for oil sent its value to high levels, many hard-to-reach sources came into production, such as the North Sea and the north slope of Alaska.

The increased flow of turquoise stirred up turmoil along the trade routes between the Southwest and Mesoamerica. Many communities along the way began to enrich themselves by exerting control over the commerce. For example, during the Late Postclassic period, the Tarascan state arose in western Mexico. This state sat astride the Pacific coast route, the most convenient for turquoise commerce. Most of the traders who worked the northern frontiers of Mesoamerica had had no problem transporting their merchandise along the coast. The Tarascans, however, began to block and thus control the traffic. Helen P. Pollard of Michigan State University suggested that the Tarascan state merchants, under royal protection, did not themselves deal in turquoise. But the many luxurious turquoise objects found in archaeological excavations at sites such as the Tarascan capital at Tzintzuntzan, Michoacán, clearly show that the stone had high value to that society. Other, smaller states thrived along the Pacific coast as well and probably added their own costs to the commerce.

Nevertheless, the coastal route endured. It did so in part because it lay along a populated corridor, whose inhabitants tended to maintain the roads. The distances from central Mexico to the northwestern periphery were considerable, but part of the way the commodities could undoubtedly take to water. As a matter of fact, Coronado followed the coastal route to the American Southwest and the adjacent Plains, which he explored in 1540.

A second, more direct inland route better served central Mexico. It led along the eastern fringes of the Sierra Madre Occidental, through lightly populated regions devoid of natural barriers, to the northwest. The disadvantage of this route, aside from aridity and distance, was that it had to be built and maintained. Strong, independent polities in western Mesoamerica could also block access to it at points in the Altos de Jalisco and the lower Lerma Valley, either to control the route for themselves or simply to deny access to the central Mexican zone.

Very well documented trade routes existed to the south, between the Culhua Mexica and the highlands of Guatemala (for jade and quetzal feathers) and between the Culhua Mexica and the *puchteca* (traveling merchant) colony at Xoconusco (for cacao). These two routes spanned impressive distances through heavily populated zones, some of whose inhabitants were forcibly subdued.

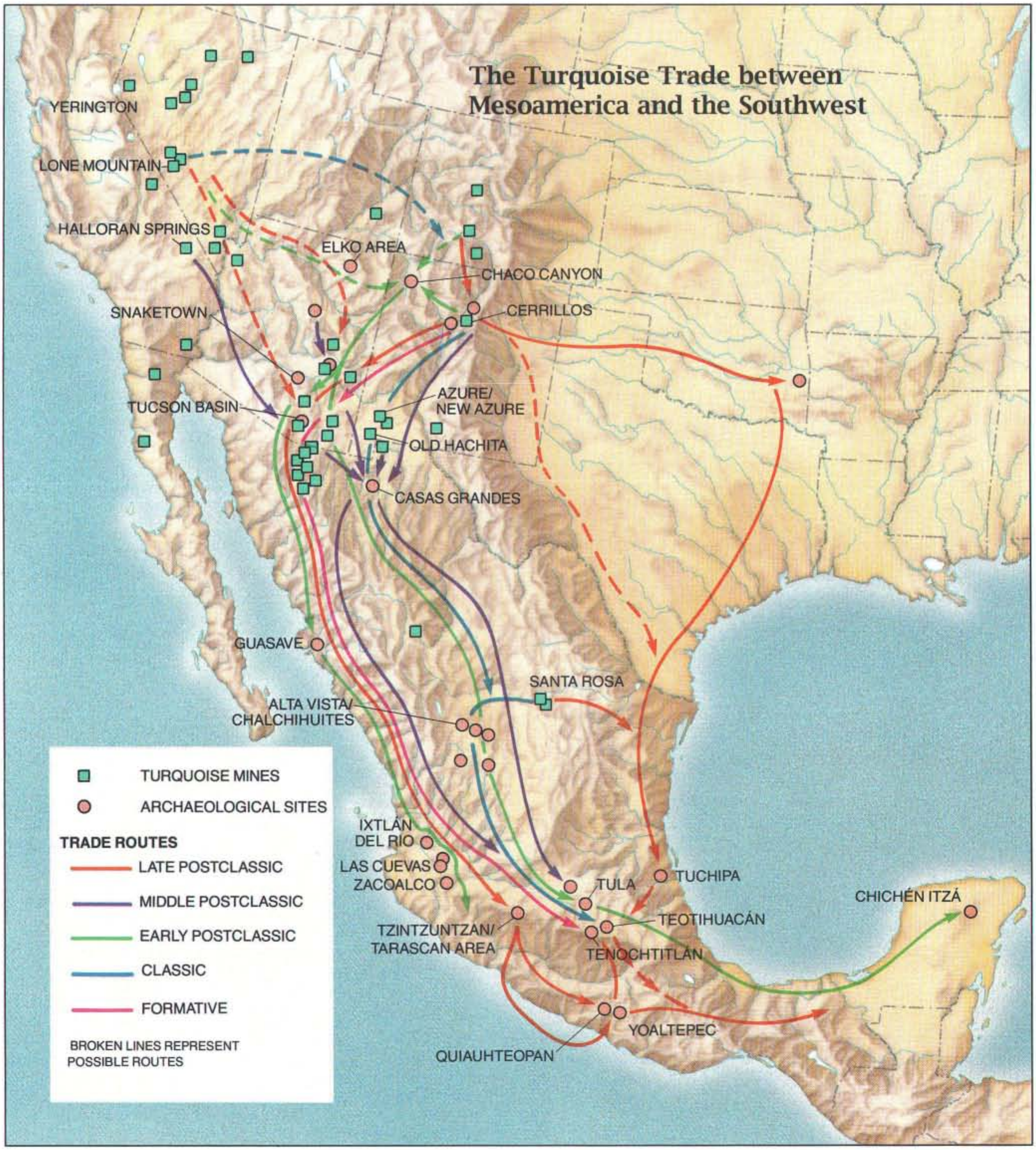
Other routes became popular as the demand for turquoise rose. We have historical evidence from the time of the Spanish conquests that the stone came to the Culhua Mexica by two quite different paths: from the provinces of Quiauhteopan and Yoaltepec, which lie due south of central Mexico, close to the Pacific coast; and from Tuchipa on the Huaxtecan coast of the Gulf of Mexico. Frances F. Berdan of California State University at San Bernardino and Patricia R. Anawalt of the Fowler Museum of Cultural History at the University of California at Los Angeles conclude in their reanalysis of the Codex Mendoza that most of the gem carried along these routes was already processed. None of the areas had deposits of turquoise, nor are there any nearby. All three provinces must have been acting as intermediaries in the transshipment.

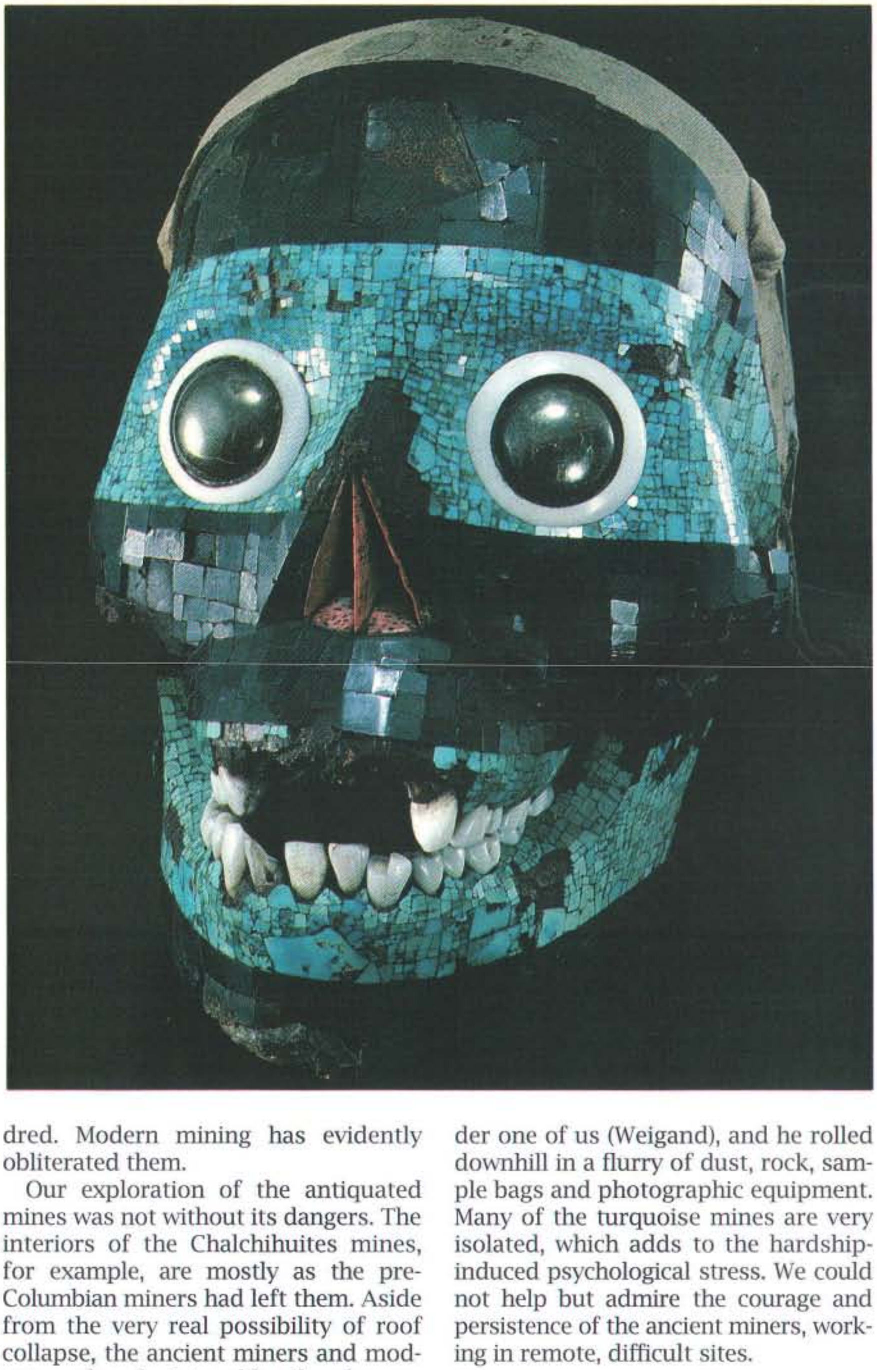
The provinces had to collect turquoise for tribute to give to the Culhua Mexica. Such tribute was probably first collected of traders passing through Tuchipa. The Codex also reveals that this province had to supply the Aztec emperor with no fewer than two round mosaics of "small turquoise stones" and one string of turquoise beads each year. Some of Tuchipa's turquoise could have come from the deposits near Concepción del Oro/Mazapil on the border between the Mexican states of Zacatecas and Coahuila. This hypothesis is consistent with the findings of Huaxtecan shards at those deposits.

Merchants plying the routes that fed turquoise to Tuchipa from the Southwest could have carried conch shell from the Gulf of Mexico in return. This particular conch has been found in late archaeological sites in the Southwest.

Apparently, even hostile states permitted the turquoise merchants to pass their borders. When the central Mexican Aztecs were at war with the Tarascans, they still managed to obtain large quantities of turquoise. In addition, turquoise was for sale in the great market of Tlatelolco, the mercantile half of the Aztec capital of Tenochtitlán; these sales were apparently independent of state control. It must be remembered that religious imperatives accounted for the demand. There was a need to construct mosaic works of ritual significance to be used in a long sequence of state ceremonies.

Social evolution and trade routes are not the only means by which to gauge the pre-Columbian demand for turquoise. The mines and the techniques used to extract the gem are also revealing. We have located some 120 preserved individual ancient mines in 28 source areas. Older descriptions documented more, perhaps many hun-


The Turquoise Trade between Mesoamerica and the Southwest



TURQUOISE MASK formed on a human skull was another of Montezuma's gifts to Cortés. It represents the god Tezcatlipoca. The eyes are made of iron pyrite and white shell, and the nasal cavity contains pieces of pink shell.

dred. Modern mining has evidently obliterated them.

Our exploration of the antiquated mines was not without its dangers. The interiors of the Chalchihuites mines, for example, are mostly as the pre-Columbian miners had left them. Aside from the very real possibility of roof collapse, the ancient miners and modern archaeologists alike faced poor working conditions: high heat and little ventilation to ameliorate air tainted by smoke from illuminating splints and dust created by excavation. In other Chalchihuites mines, we encountered thousands of tiny insects living in the bat guano. The smell of bats and guano is bad enough, but, in addition, some of these insects regarded humans as a source of food. They swarmed up our pant legs and over our arms and faces as we crawled through the corridors.

One contemporary mine we investigated, which was dug into a more venerable one, was called the Metallic Accident. We should have been forewarned. The upper talus platform collapsed under one of us (Weigand), and he rolled downhill in a flurry of dust, rock, sample bags and photographic equipment. Many of the turquoise mines are very isolated, which adds to the hardship-induced psychological stress. We could not help but admire the courage and persistence of the ancient miners, working in remote, difficult sites.

Retrieving the turquoise itself must have been challenging. Most of the raw material occurs in deposits of hard rock, so extracting stone from stone is arduous and time-consuming. One can find evidence, cited by J. E. Pogue in his 1915 classic work *The Turquois,* that fires were built on the stone face, heating the rock. Water dashed onto the surface cracked open the turquoise-bearing veins. This kind of extraction obviously required bringing plentiful quantities of water and firewood to the mining site. Usually the miners just swung stone mauls at the unyielding rock surface—grueling work in a hot climate. The engineering of most mines was quite rudimentary. Only a few examples of truly complex chambering, like that which characterizes the Chalchihuites mines, are documented.

Instead deposits close to the surface were exploited first, by digging simple pits or quarries. Actual mines were begun only when turquoise in these shallow deposits was exhausted. Most such sites consist of the simple shaft-chamber mines we found in large numbers at the Hachita, N.M., complex. Sometimes, however, these mines were expanded into huge open-face pits. The pit at Mount Chalchihuitl in the Cerrillos mining area of New Mexico is certainly the best known and documented, but there are others, such as the Toltec mine in the Mojave Desert.

The hammerstones recovered from the old turquoise mines do not show much technical specialization. Three-quarter grooved mauls, which were double-headed, were the most common implement. Their throw weight was considerable, and the unmistakable evidence of the miners' sheer persistence on the job tells us how enormously valuable the product must have been.

We might guess that the attitude of many Native Americans toward the gemstone matched that of Shakespeare's Shylock. Told that his runaway daughter had traded one of his rings for a monkey, Shylock burst out, "It was my turquoise: I had it of Leah when I was a bachelor. I would not have given it for a wilderness of monkeys."

FURTHER READING

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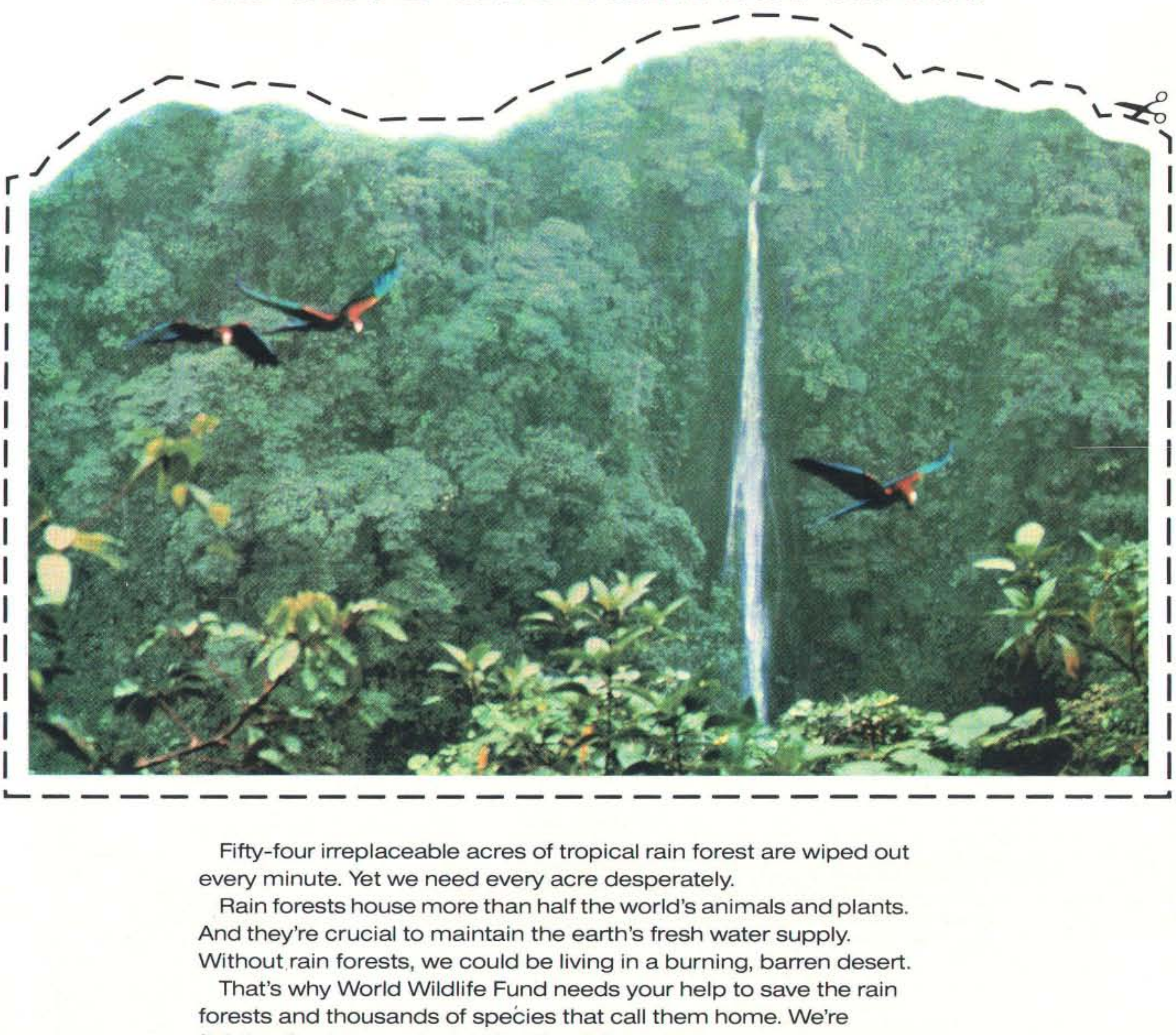

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Nikolai V. Timoféeff-Ressovsky

Controversy surrounds this Russian-born geneticist, whose major scientific achievements were made in Nazi Germany and who was later convicted of treason by the Soviet Union

by Diane B. Paul and Costas B. Krimbas

In 1925 Oskar Vogt, the director of the Kaiser Wilhelm Institute for Brain Research in Berlin, invited a promising young Russian researcher named Nikolai V. Timoféeff-Ressovsky to organize a department of experimental genetics there. Timoféeff, who was 25, did not even possess an undergraduate degree at the time. Yet within a few years, he was to become director of the new department and a leading figure in the fields of population and radiation genetics.

Specifically, Timoféeff helped to develop an influential theory of how mutations occur, he made the first measurement of a gene, and he established that much of the genetic diversity in a wild population is hidden in the form of recessive mutations. Although histories of genetics hardly mention Timoféeff, he significantly influenced genetic research not only through his own work but also by transmitting Russian ideas about the mechanism of evolution to the West.

These achievements were all the more remarkable given the troubled, paradoxical political circumstances of his life. He was a Russian patriot, but Timoféeff's most scientifically productive years were spent in Germany before and during the Nazi era. When Soviet troops entered Berlin at the end of World War II, he was imprisoned. Because of his expertise in radiation biology, he was allowed to continue his genetic studies in a military laboratory at a time when such research had been publicly banned in the U.S.S.R. Nevertheless, he was hounded by political opponents for the rest of his life and has never been rehabilitated.

DIANE B. PAUL and COSTAS B. KRIMBAS have collaborated in research on the history of genetics. Paul is a professor of political science at the University of Massachusetts at Boston and a research associate at the Museum of Comparative Zoology at Harvard University. She received her Ph.D. from Brandeis University in 1975. From 1988 to 1989 she was a fellow at the Wissenschaftskolleg zu Berlin, where she researched much of this article. A collection of Paul's essays will be published next year. Krimbas is a professor of genetics at the Agricultural University of Athens. He earned degrees at the University of Lausanne in Switzerland, at the Sorbonne in Paris, and at Columbia University, where he studied genetics under Theodosius Dobzhansky.

Timoféeff's life poses difficult questions: How could a scientist work honestly in an environment of ideological and physical warfare? Was it possible to be a geneticist in Nazi Germany without being morally compromised? And how can one distinguish an independent researcher from a discreet collaborator? We set out to investigate these issues and to learn more about Timoféeff's fascinating political and intellectual life.

Political upheaval interfered with Timoféeff's research from the start. The October Revolution erupted while he was a biology student at Moscow University. Timoféeff left school to fight with the anarchists and later with the Red Army (he did not formally complete his doctorate until 1964). In 1922 he returned to the university, where he studied with Sergei S. Chetverikov, the founder of Russian population genetics. Chetverikov instilled in Timoféeff an abiding interest in the genetic basis of evolution. At the same time, Timoféeff began working with Nikolai K. Kol'tsov, the head of the Research Institute for Experimental Biology. Kol'tsov grounded the young Timoféeff in the methods of comparative anatomy, morphology and systematics. This intellectual mixture proved instrumental in guiding Timoféeff's later scientific work.

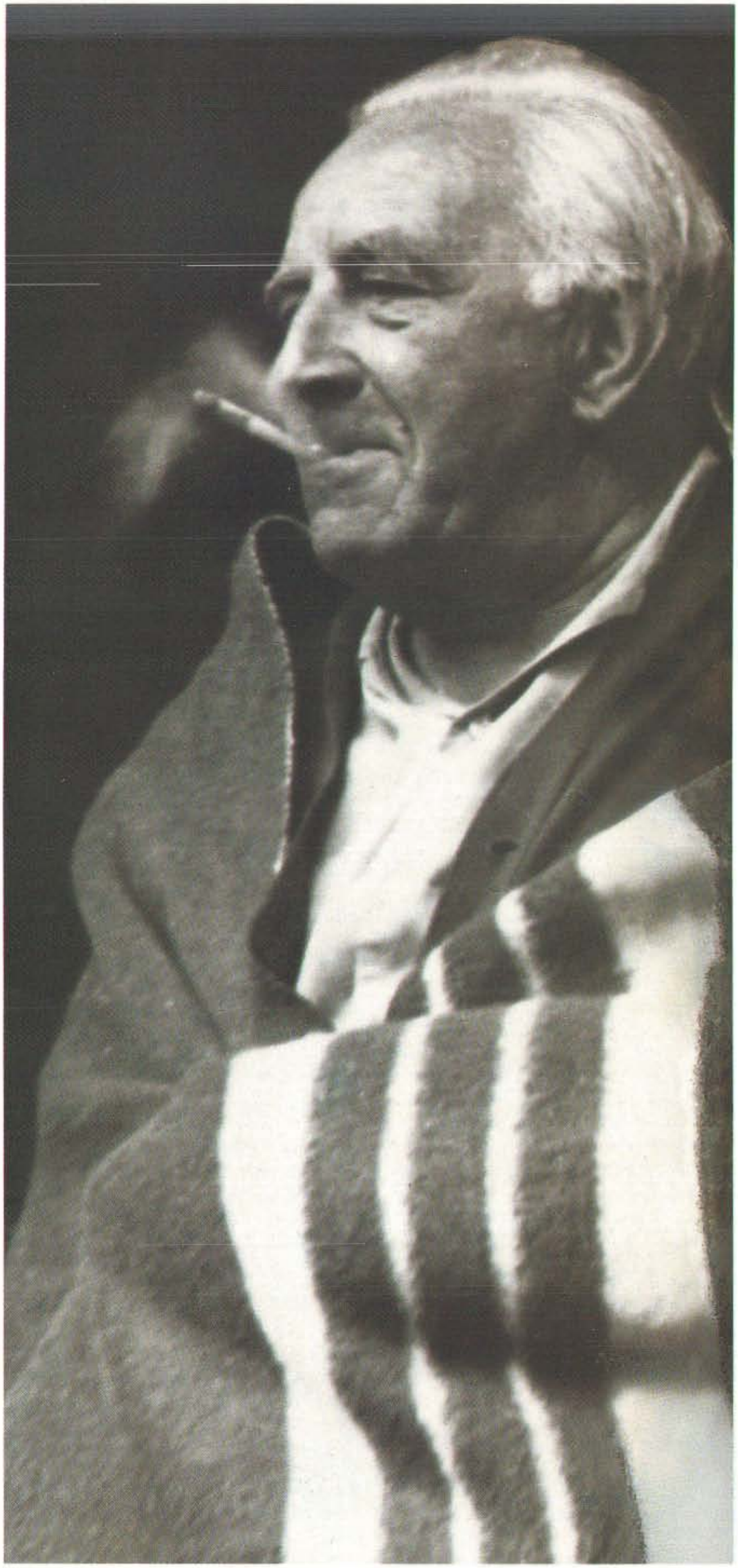
A curious set of circumstances prompted Timoféeff to leave Russia and move to Berlin in 1926. After Lenin's death in 1924, the Soviet government arranged for a microscopic study of its deceased leader's brain, ostensibly to uncover the material basis for his genius. The Soviets invited Vogt, a noted German psychiatrist and neurophysiologist, to direct the work.

While in Russia, Vogt learned that Timoféeff and his wife, Helena Aleksandrovna, had found a mutation in the fruit fly species *Drosophila funebris* that produced highly variable deformations in a vein in the fly's wings. At the time, Vogt was trying to determine why certain inherited neurologic disorders vary tremendously in frequency and severity. The discovery that a single kind of mutation could produce many different wing morphologies therefore caught Vogt's attention.

He invited Timoféeff to organize a new genetics laboratory being started at Vogt's institute. Despite his strong emotional ties to Kol'tsov and to his homeland, Timoféeff accepted and moved to Berlin. At that point, he had published a few papers but was essentially unknown outside of a small circle of Russian biologists. In the years between his arrival in Berlin and the outbreak of war, Timoféeff produced nearly all the work on which his scientific reputation rests.

Timoféeff's primary interest lay in understanding the process of evolution. When he moved to Berlin, he brought to Germany and western Europe the ideas of Chetverikov, who had developed an innovative synthesis of Mendelian genetics and classical Darwinism. Chetverikov arrived at his ideas independently of the British geneticists Sir Ronald A. Fisher and J.B.S. Haldane and the American Sewall Wright, who in the West are considered the founders of the neo-Darwinian school. The American evolutionist Ernst Mayr states that Timoféeff was largely responsible for the evolutionary synthesis that occurred in Germany in the 1930s.

TIMOFÉEFF-RESSOVSKY remained scientifically active throughout his tumultuous life. Here he is seen between lectures at Lake Miassovo in the 1960s.



Timoféeff's research group at the institute included prominent Russian, German, Romanian and Greek geneticists, who helped spread his influence. He also received a number of notable visitors, among them the population geneticist Adriano Buzzati-Traverso, who once brought along his students Luigi Luca Cavalli-Sforza (now a geneticist at Stanford University) and G. E. Magni (now at the University of Pavia in Italy). Buzzati-Traverso in turn influenced Antonio Prevosti of the University of Barcelona and, through him, a significant group of Spanish population geneticists.

According to the neo-Darwinian view that shaped Timoféeff's work, natural selection can act only when genetic variability—which is generated by mutations—is present. Members of a population, whether birch trees, sparrows or fruit flies, usually show remarkable morphological constancy. Genetic variability is concealed because each individual has two sets of genes, one inherited from the male, the other from the female parent. Most mutations are recessive and therefore are not manifested in individuals who also possess a normal ("wild type") form of the gene. Chetverikov understood that because of this hidden store of variability, selection need not wait for the appearance of new mutations; they are already present in recessive genes in the population.

Timoféeff and his wife studied a natural population of the fruit fly *Drosophila melanogaster* to prove experimentally what their teacher had surmised. By inbreeding flies caught in nature, they produced individuals in which both genes encoded the recessive mutant trait. Their paper, published in 1927, offered the first proof of the existence of significant amounts of concealed genetic variability.

Timoféeff was guided to another important area of research by the Russian neo-Darwinian school's emphasis on the relation between genotype (the genetic constitution of an individual) and phenotype (its observable morphology, physiology and behavior). Being good naturalists, the Russians knew that natural selection targets the phenotype. Its relation to the genotype therefore is of primary importance for understanding how genetic changes occur in a population. Timoféeff and his wife, along with the Russian-born American geneticist Theodosius Dobzhansky, were among the first to study phenomena such as pleiotropy (the manifestation of a gene in more than one characteristic), as well as penetrance and expressivity (the frequency and degree, respectively, to which a gene is manifested).

These studies bolstered the view that

The Strange Career of Timoféeff-Ressovsky

The young **Timoféeff** (*a*) benefited from an education that prepared him both as a field naturalist and as a mathematical population geneticist. His teacher **Chetverikov** (*b*) helped him to recognize the connection between mutations, genetic variability and natural selection. The death of **Lenin** (*c*) in 1924 signaled a turning point in Timoféeff's career. **Vogt**, seen here with his wife (*d*), came from Germany to the Soviet Union to study Lenin's brain. There he met Timoféeff and offered him a position at the Kaiser Wilhelm Institute for Brain Research in Berlin. In 1926 Timoféeff moved to Germany, where he conducted his most significant research. Much of his work focused on understanding the nature of genetic variation; to this end he worked extensively with X rays. At one point, he collaborated with **Muller** (*e*), who later won the Nobel Prize for his discovery that X rays produce mutations.

several genes can influence the same characteristic, such as fecundity, and that the combined action of two mutant genes cannot necessarily be predicted by their actions when only one is present. Thus, geneticists came to realize that the genetic variability of a population should be viewed not as a group of noninteracting genetic entities (a model labeled "bean bag" genetics by Mayr) but as an integrated, cohesive whole.

Early in the 20th century many geneticists, following the ideas of the British biologist William Bateson, believed that recessive mutations resulted from irreversible genetic damage or loss. This view implied that evolution could not proceed further, because all mutations would lead to a reduction and loss of usable genetic material. Timoféeff demonstrated that mutant strains can undergo additional mutations, eventually reverting to dominant, wild-type forms. These so-called back mutations would be impossible if the appearance of a mutant were caused by a loss of genetic material.

One way to increase mutation rates is to irradiate organisms with X rays, a phenomenon first documented in 1927 by the American geneticist Hermann J. Muller. As a result of his student years in Russia, Timoféeff was inclined to use experimental techniques; he readily incorporated X ray–driven mutations in his studies. Some of his most important scientific achievements derived from his efforts to understand how X rays cause mutations.

Timoféeff's principal discovery was his observation of a linear relation between the total radiation dose and the number of mutations. Whether the dose was administered in a single shot, in several fractions or continuously at a low level over an extended period appeared irrelevant. The intensity of the dose did not affect the number of mutations produced. He also found no minimum dose below which mutations were not generated.

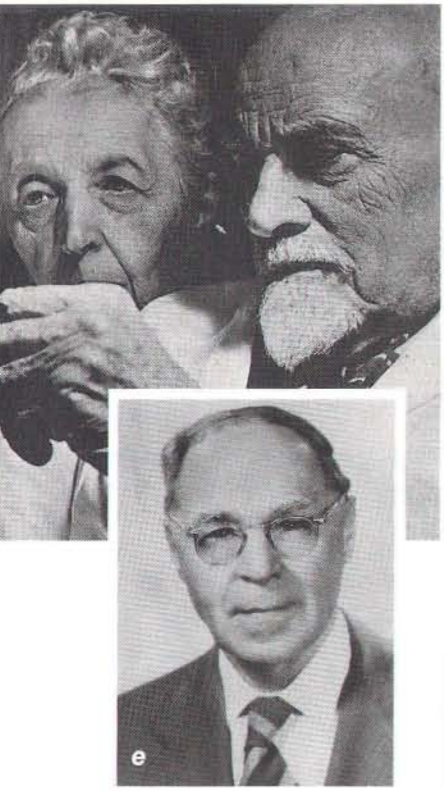
These properties suggested that X rays produce mutations much like bombs hitting targets. Timoféeff, along with his German co-workers Karl G. Zimmer and Max Delbrück, set out the target—or hit—theory based on this analogy. The classic "three-man paper" describing their work inspired Erwin Schrödinger to deliver his 1943 course of lectures, later published as the book *What Is Life?*, which helped draw many physicists to molecular biology.

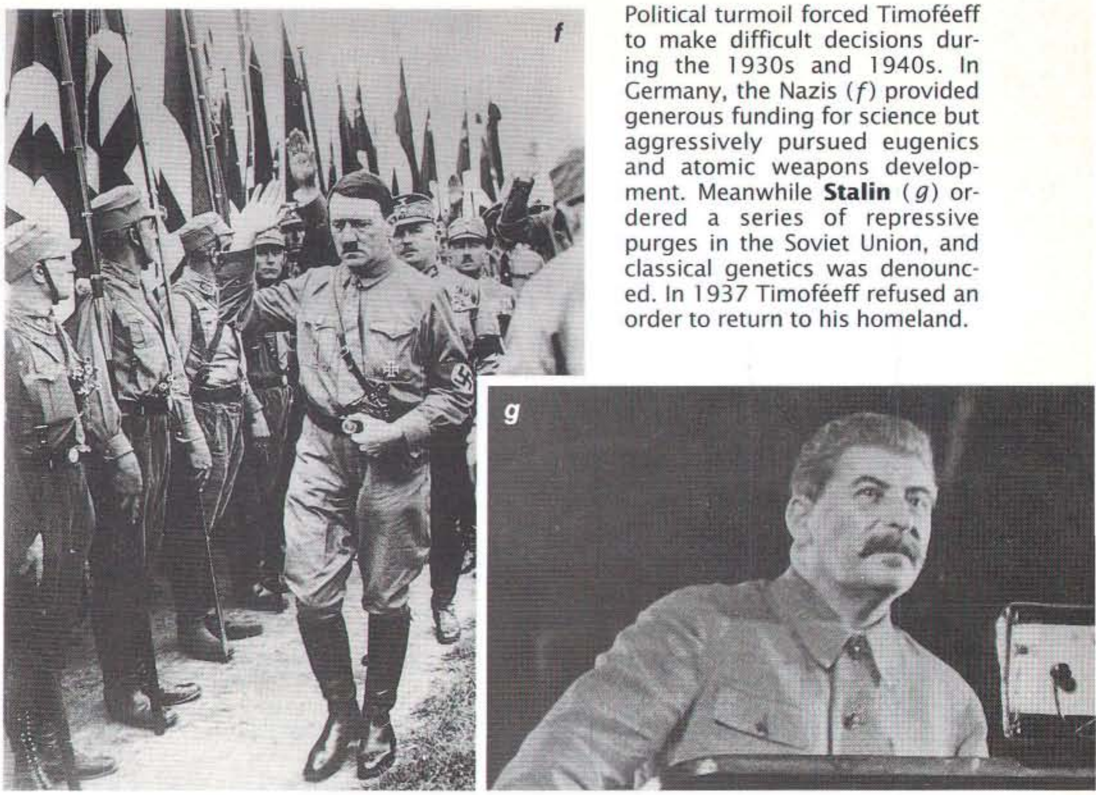
In the target model, an X-ray photon expels electrons from atoms. These unbound electrons hit other atoms, dislocating more electrons, and so on. The free electrons eventually settle in the electron shells of other atoms. In this way, an X ray creates positively charged ions (atoms missing electrons) and negatively charged ones (atoms having a surplus of electrons). One ionization in a gene causes a mutation.

Timoféeff and his collaborators set out to estimate the size of a single gene by calculating the number of ionizations produced in a certain volume of tissue and by recording the increased number of mutations of a particular gene in that tissue. Timoféeff and his co-workers found the gene to be a sphere one to 10 microns across.

However crude this estimate may now seem, it had a tremendous conceptual impact at the time. Thomas H. Morgan's group at Columbia University demonstrated in 1910 that genes are located at fixed positions on chromosomes. Timoféeff rendered this description more precise: the gene has the dimensions of a large organic molecule.

One might expect that Timoféeff's group would have identified the hereditary molecule as being DNA. Investigators studying mutations caused by ultraviolet rays had already uncovered evidence pointing in that direction. Ultraviolet rays vary in their ability to cause mutations depending on their wavelength. Different substances have their own specific spectrum of absorption of ultraviolet rays. Starting in the mid-1930s in Germany and in the early





Political turmoil forced Timoféeff to make difficult decisions during the 1930s and 1940s. In Germany, the Nazis (*f*) provided generous funding for science but aggressively pursued eugenics and atomic weapons development. Meanwhile **Stalin** (*g*) ordered a series of repressive purges in the Soviet Union, and classical genetics was denounced. In 1937 Timoféeff refused an order to return to his homeland.

1940s in the U.S., researchers found that the ultraviolet wavelengths that most efficiently caused mutations corresponded to the absorption spectrum of DNA.

Biologists knew that chromosomes consisted of DNA and proteins. But nobody, Timoféeff included, suggested that the gene might be composed of DNA. Instead proteins were the favorite candidate for the molecule making up the gene. Two reasons led to that confusion. First, chemists at the time thought DNA had an invariant molecular structure. It seemed impossible that such a molecule could form the enormous range of genetic entities.

Second, in Germany knowledge of the chemistry of proteins was far more advanced than that of nucleic acids. By the 1930s many aspects of protein structure were understood. Geneticists knew that many different proteins could be constructed by combining the 20 kinds of amino acids in various linear assemblies. In 1932 the organic chemists Max Bergmann and Leonidas Zervas invented a method for synthesizing any small sequence of amino acids.

These prejudices and misconceptions prevented Timoféeff from recognizing the significance of the ultraviolet absorption spectrum of DNA. Until the fall of Berlin in 1945, his student Anton Kanellis worked on the relation between dose and number of mutations produced by ultraviolet rays but did not look at the effect of wavelength.

It is worth noting, however, that James Watson, who along with Francis Crick co-discovered the double-helix structure of DNA, was a student of Salvador E. Luria. Luria in turn closely collaborated with Delbrück, Timoféeff's co-author on the three-man paper. Thus, Timoféeff's intellectual legacy eventually contributed to the greatest biological discovery in this century.

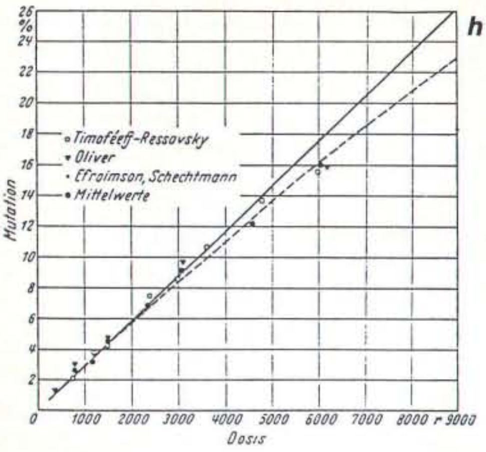
Timoféeff's scientific productivity during his years in Germany belies the difficult decisions forced on him by the political situation there and in the Soviet Union during the 1930s and 1940s. After the Nazis assumed power in 1933, they expanded support for genetic research but also required obeisance to the new regime. During the same period, Soviet officials had suggested several times that Timoféeff should return home. In 1937 they ordered him to do so. Timoféeff refused.

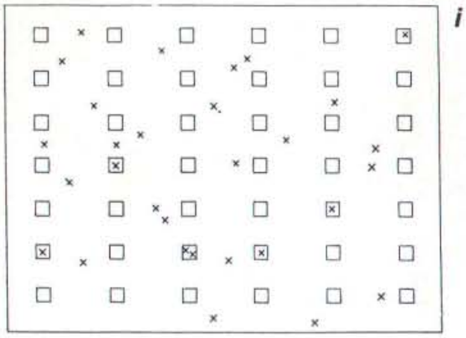
His decision in part reflected the deteriorating situation in the Soviet Union. Under the peasant agronomist Trofim D. Lysenko, the study of Mendelian genetics was outlawed in favor of his own belief that evolution occurs primarily through the inheritance of acquired traits. Kol'tsov had been dismissed as director of his institute, and Chetverikov had been arrested and exiled. The wider Stalinist terror was also well under way. In the mid-1930s two of Timoféeff's younger brothers and many of his wife's relatives were arrested; one of his brothers was executed. Thinking that Timoféeff might obey the order to return, Kol'tsov reportedly warned him, "Of all the methods of suicide, you have chosen the most agonizing and difficult. And this not only for yourself, but also for your family."

Timoféeff had other options, including an opportunity to work in the U.S. The Institute for Brain Research had long-standing ties to the Rockefeller Foundation. When informed that Timoféeff might be considering leaving Nazi Germany, the foundation helped to negotiate an offer of a position with the Carnegie Institution in Cold Spring Harbor on Long Island. To their surprise, he declined.

Timoféeff cited his responsibilities to co-workers and technical assistants who would lose their jobs if he left, qualms over moving his family and the inferior technical support—and social status—accorded to professors in America. "I heard that America too is getting chauvinistic," he added. He had commented to the French physicist Charles Peyrou that the working conditions of scientists in the U.S. were poor.

Like many a contemporary academic,





Mutation research by Timoféeff and others revealed a linear relation between X-ray dose and number of mutations (*h*). The target theory (*i*), published in 1937 by Timoféeff along with **Zimmer** and **Delbrück** (*j*), held that X rays cause mutations much the way randomly thrown bombs hit targets. This work enabled Timoféeff to make a crude but influential estimate of the size of a gene.

Timoféeff used the American offer to negotiate an improvement in his position at the Institute for Brain Research. The institute granted his department virtual autonomy, in everything except material requests. Timoféeff's independence later was further enhanced by his collaborations with scientists at the Auer Society, a huge chemical concern that was directly involved in war work and, in particular, with the production of uranium for the German atomic project. When Germany declared war on the U.S.S.R. in 1941, the possibility of returning home vanished.

At the end of World War II, the staff of the brain research institute was evacuated to Göttingen. Again, Timoféeff could have fled but instead chose to remain in Berlin, where he and a handful of his co-workers awaited the arrival of the Red Army. Some friends believe that Timoféeff expected to be acknowledged as an anti-Nazi. Furthermore, many German scientists, including Timoféeff, had speculated that it was better to collaborate with the Russians, who needed scientists, than with the Americans, who needed no one. He was in any case extremely reluctant to move to the West. Delbrück believed that Timoféeff knew he would be arrested but preferred serving a sentence in the U.S.S.R. to becoming a refugee. On the night before the Red Army arrived, Timoféeff told Peyrou that he realized his decision to stay in Berlin might prove fatal.

When the Soviet troops arrived, Timoféeff was arrested, but Avrami P. Zavenyagin, the deputy commissar of internal affairs, soon ordered him released. Zavenyagin recognized that Timoféeff's research in radiobiology and radiation genetics could be important for the Soviet atomic project. Timoféeff's situation changed yet again when a delegation from the Moscow Academy of Sciences arrived and ordered him rearrested.

This time Timoféeff was imprisoned. At one point, he was incarcerated in the same prison as Alexander Solzhenitsyn, who described in *The Gulag Archipelago* the scientific seminars that Timoféeff organized there. After a few months, Timoféeff was transferred to a labor camp in North Kazakhstan. For two years, his friends and family were unable to learn where he was or even whether he was alive.

Fortunately, Zavenyagin still had plans of his own. After a prolonged search, he finally located Timoféeff, who by then was close to death from starvation and nearly blind from vitamin A deficiency (he never fully regained his sight). In 1947 Timoféeff was transferred to a secret military research center near Sverdlovsk, in the Ural Mountains, where he organized a radiation biology laboratory. His wife and second son, along with some former co-workers, received word to join him.

During the next decade, Timoféeff developed the new field of radiation biogeocenology, the analysis of the distribution, accumulation and migration of radioactive isotopes in experimental and natural biological systems. Because of the secret nature of his work, he was one of the few Soviet scientists allowed to continue genetic research while Lysenko was in power.

In 1955, two years after Stalin's death, Timoféeff received amnesty. He moved to Sverdlovsk, where he organized a biophysics laboratory at the Ural Division of the Academy of Sciences; he also founded an experimental station and summer school at nearby Lake Miassovo. This school played a crucial role in keeping the tradition of classical genetics alive during Lysenko's reign. In 1964 Timoféeff moved to Obninsk (50 miles southwest of Moscow) to organize a department of genetics and radiobiology at the new Institute of Medical Radiology.

Although he received awards from several foreign scientific societies, Timoféeff was never allowed to travel abroad; he was also largely prohibited from publishing in popular scientific journals. At home, Timoféeff became something of a cult figure, but his con-

Soviet biological research from the 1930s to the 1960s was severely distorted by **Lysenko**, who did not believe in Mendelian genetics (left side of *k*, where he is shown with **Khrushchev,** and of *l*). After World War II, the Soviet government arrested Timoféeff for having remained in an enemy country. For part of this time, he was imprisoned alongside **Solzhenitsyn**; the two are seen here years later (*m*). Timoféeff eventually received amnesty and continued his research until his death in 1981. In the l960s he lectured at Lake Miassovo (*n*).

tinued public pronouncements on genetics earned the wrath of Lysenkoists. Even in 1968, four years after Lysenko lost his formal authority, Lysenkoists blocked Timoféeff's nomination to the Soviet Academy of Sciences. They accused him of having been a Nazi collaborator and of having conducted experiments on Soviet prisoners of war.

Two years later Timoféeff's opponents pressured him into retirement from the Institute of Medical Radiology. He then consulted at the Institutes of Medical Biological Problems and of Developmental Biology, where he studied space medicine and continued his genetic research until his death in 1981.

In the wake of historic political shifts in Germany and the Soviet Union, Timoféeff's experiences seem especially compelling. In fact, there has been a recent surge of interest in Timoféeff. A series of Soviet documentary movies on Timoféeff has enjoyed great success. In 1987 Daniil Granin, a distinguished Russian science writer and friend of Timoféeff, published *Zubr* (*The Bison*), a novel in which he portrayed Timoféeff as a heroic victim of Stalinism and Lysenkoism. The ensuing debate grew so intense and bitter that the German edition of *The Bison* was not distributed in East Germany.

One of the most pressing questions about Timoféeff, especially in Germany, has been whether he collaborated with the Nazis. In a passionate article, Raissa L. Berg, a Russian-born geneticist who knew Timoféeff in the Soviet Union, asserts that he "stands beside Galileo and other great scientists persecuted by the authorities of their time." She is one of a number of commentators in Germany, the U.S. and the U.S.S.R. who view Timoféeff as an overt anti-Nazi who spent the war years engaged in pure research.

The critic Oliver Tolmein, in contrast, believes Timoféeff was deeply involved with both racial hygiene research and the construction of an atomic weapon. Tolmein's opinion is that historical truth has been "sacrificed on the altar of anti-Stalinism": whoever opposed Stalin must be a hero, however lamentable his other activities or values.

Benno Müller-Hill, a geneticist at the University of Cologne, struck an intermediate tone in his review of *The Bison.* He argues that Timoféeff was a complicated character who helped many endangered people but also occasionally dressed technical science in the garb of racial hygiene and directed his research toward areas favored by the Nazi regime. Müller-Hill's review provoked a heated response from two Soviet biologists, who argued that if Timoféeff was not a villain, he must have been a hero, because those are the only possibilities in a totalitarian society.

Timoféeff was among the minority of biologists who did not join the Nazi party or its affiliated organizations. He refused German citizenship, even when pressured by his German superiors. He told Peyrou of his response: "Sir, I am born a Russian, and I do not see any way to change that fact." Natascha Kromm, Timoféeff's assistant at the institute, described him as "more than a Russian patriot—a chauvinist." He openly boasted of Soviet strength in the war with Germany, comments that led to a reprimand from the Kaiser Wilhelm Society's secretary general.

After 1943, Timoféeff had particular reason to hate the Nazis. That year, his eldest son, Dmitri, who was involved with the resistance, was arrested. Despite his father's intense efforts to save him, Dmitri perished in the concentration camp at Mauthausen in 1944.

Especially significant is the fact that Timoféeff was one of a handful of scientists in Germany who helped to protect the persecuted, including people of Jewish descent, Russian refugees, prisoners of war and *zwangesarbeiter,* foreigners drafted to work in German factories. The Kaiser Wilhelm Institutes in Berlin were classified as *kriegswichtig,* or important to the war effort, which qualified them to apply for laborers.

Timoféeff was able to have several prisoners and drafted workers reassigned to his genetics department on the basis of grossly inflated claims about their qualifications and potential contribution to the war effort. For some workers, it was also necessary to forge identity papers and other documents.

It is difficult to know what to make of Timoféeff's decision to continue his research in Nazi Germany. With the advantage of hindsight, it is obvious that he should have accepted the invitation to go to Cold Spring Harbor or that he should have tried to find a position elsewhere in Europe. But in the mid-1930s even some Jewish scientists were reluctant to leave Germany; for example, the geneticist Richard Goldschmidt left only after he was forcibly retired from his directorial position at the Kaiser Wilhelm Institute.

That said, Timoféeff's decision to stay was ipso facto a decision to cooperate with the Nazis. At minimum, it meant lending his scientific prestige to the regime in exchange for the considerable support the Nazis accorded to scientific research, especially experimental mutation research.

Overall, the political pressures on scientists in Nazi Germany were remarkably slight. Scientists did not have to become party members to obtain grants for biological research; Ute Deichmann and Müller-Hill have shown that party membership did not even necessarily confer an advantage. Timoféeff had acquired tremendous independence for his laboratory. And the Institute for Brain Research was located in the suburbs of Berlin, where the Nazi presence was somewhat less overbearing.

Even so, German politics necessarily intruded into life within the institute. In May 1933 the Nazi civil service law was extended to the Kaiser Wilhelm Society. All Jews were immediately dismissed except for institute directors, who were allowed to continue through 1935. Vogt, the director of Timoféeff's own institute, was forced from his position in 1936 because of his anti-Nazi sympathies.

The Nazis' presence is also revealed in various compromises that Timoféeff made with the regime. He participated in a course of lectures for S. S. doctors, although he apparently only gave technical lectures on mutation research. He signed official correspondence "Heil Hitler." Timoféeff occasionally published in Nazi medical journals such as *Zeil und Weg* (*Ends and Means*) and *Der Erbarzt* (*The Genetic Doctor*), in which he wrote of the need to identify the heterozygous carriers of genetic diseases, those having one mutant set of genes. Because most deleterious genes are hidden in apparently normal individuals, he explained, an effective program to reduce the incidence of genetic disease requires a method to detect such carriers.

Timoféeff never specified what measures should have been taken if these carriers were identified. Even so, such research seemed to lend support to Nazi racial hygiene theories, which pronounced the importance of purifying the German genetic stock. The Nazis used that doctrine as a rationale for exterminating "impure" people, particularly the Jews. Timoféeff's research on radiation biology was also seen as relevant to understanding the possible effects of atomic weapons on a human population.

Timoféeff's relation with the Auer Society and with researchers at the Kaiser Wilhelm Institute for Physics has inspired charges that he was involved with the German atomic project. Timoféeff's group at the Institute for Brain Research did pursue studies of radiologic protection and neutron-dosimetry that were financed by Walter Gerlach, the director of Germany's program of atomic research. But the atomic project was not simply an effort to build a bomb; rather, it was a broad enterprise that included many civilian applications, such as the generation of nuclear energy. Timoféeff seems never to have been directly involved in weapons development, although he worked with people who were.

Timoféeff was closely associated with a number of scientists, including Nikolas Riehl (the Russian-born chief chemist of the Auer Society) and the physicist Pascual Jordan, who worked on weapons-related research. Riehl insists that their work connections arose from the fact that many physicists were interested in biophysical problems and that Timoféeff had "no relationship whatsoever" to weapons development.

Perhaps the most serious charge against Timoféeff originated with a remark in Müller-Hill's review of *The Bison.* Müller-Hill noted that some of Timoféeff's collaborators injected human subjects with radioactive thorium X (now known as radium 222) to find out how long it would remain in the body. These experiments were conducted at Timoféeff's institute and with his knowledge. The researchers did not identify their subjects or say how large a dose they injected.

The idea that the dosage was kept secret has gained wide currency even though at least two published articles explicitly state that the experiments involved a dose of about 30 microcuries of thorium X. One Soviet author recently calculated that the administered dose of thorium X would have been lethal. He based this shocking claim on a set of radiation standards published by R. D. Evans, a leading authority on radiation therapy. But Evans examined the effects of exposure to radium 226, which has a half-life of 1,600 years; the half-life of thorium X, in comparison, is 3.64 days. Because of its long half-life, radium 226 releases a vastly greater total amount of radiation during the time it resides in the body. In fact, Evans reports that a dose of 30 microcuries of thorium X should produce no significant health effects.

The controversy over Timoféeff's actions continues to the present. In 1988 the Soviet government denied an application for his rehabilitation on the grounds that Timoféeff had conducted research that enhanced Fascist military power and that he therefore had "betrayed the motherland by going over to the side of the enemy." But on October 16, 1991, the procurator general of the U.S.S.R. asserted that there had been no legal basis for the original charge of treason issued in 1946.

Whatever the ultimate legal and moral judgment on Timoféeff, his scientific achievements are undeniable. He made noteworthy contributions to the understanding of the nature of the gene, genetic variability and the biological effects of exposure to radiation, work whose value has not been adequately acknowledged in the West.

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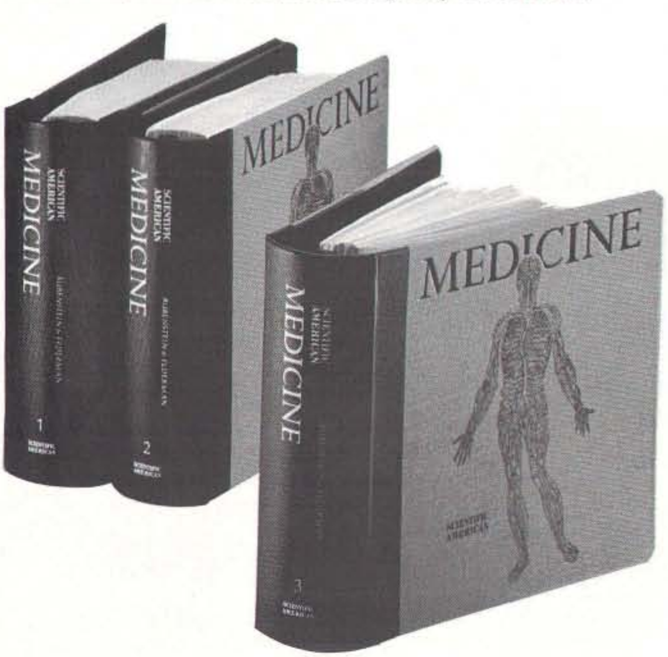

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PICTURE PERFECT

by Elizabeth Corcoran, *staff writer*

EDITORS AND ENGINEERS practice creating high-definition programs in preparation for the 1992 Winter Olympic Games, beginning in February in Albertville, France.

Europe has bet heavily on HDTV. The outcome may presage whether 1992 will mark the emergence of a unified technological power.

The flame of the Olympic torch and the first blanket of snow had yet to reach Albertville, France, in early November. Within months, such wintry scenes would fill television screens around the world as viewers tuned in to watch the opening of the 1992 Olympic Games on February 8. But in the meantime, as ice skaters tried out tentative leaps and pirouettes on the new rinks, a handful of European television engineers was already scrambling with cameras and video vans, preparing to roll tape.

The technicians were the point men of a crew of 350 who will broadcast more than 12 hours a day of Olympic Games using the European Community's new high-definition television (HDTV) system. Organizers hope people will flock to specially equipped viewing sites to watch the competition unfold on giant screens that deliver images with a clarity approaching that of a 35-millimeter movie. After the Winter Games, the technicians will pack their gear and head off to broadcast the Summer Olympics in Barcelona, as well as Expo '92 in Seville.

That these broadcasts will be airing the Olympic Games in 1992 carries double significance. This year marks the realization of more than three decades of diplomacy aimed at forging Europe into a single economy—the world's largest market, with 340 million consumers. What is more, the Olympics have long marked television milestones. Black-and-white television debuted at the Berlin Games in 1936. The 1968 Games in Grenoble introduced European viewers to color.

For EC planners, the push into HDTV also signifies a major test of whether an economically unified Europe can stimulate the growth of robust, high-technology companies, enabling them to compete with the best of the Pacific Rim and North America and to catalyze the economic rebirth of the former Eastern bloc. Since 1986, the Europeans have spent roughly $1 billion to create a homegrown HDTV system in an intense industrial research effort called Eureka, funded by national governments and the EC. "With all the cultural differences, Europe is building an infrastructure that is European," declares Peter J. Groenenboom, senior managing director of Philips Consumer Electronics.

Yet the success of Europe's efforts to piece together such an infrastructure depends on a battery of questions: Can the managers and engineers of French, English, Dutch, German and Italian and other corporations cooperate to propel the technology out of the laboratory and convert it into consumer products? Will the development of HDTV spur innovation in other key industries, from semiconductors to automobiles? Will the broadcast and other standards set by the EC effectively lock out foreign competitors or create an opportunity for Japan and others? And, ultimately, will the consumers buy the new technology?

The answers to those questions will resonate in both Washington, D.C., and Tokyo. Japanese manufacturers are still patiently waiting for their chance to make a play for the European market. U.S. industrialists, shaken by the collapse of their consumer electronics industry, are watching to see whether an industrial policy that orchestrates the public and private sectors can come from behind for a win.

European planners did not expect to kick off the race toward HDTV six years ago, nor did they envision how HDTV would draw together various "national champion" companies. Instead Japan—and in particular the state-owned Japan Broadcasting Company (NHK)—was the incubator for theories about a new generation of television.

Beginning in the early 1970s, NHK researchers began experimenting with ways to improve television. In a battery of psycho-optic tests, they found that widening the width to height, or aspect, ratio from the conventional boxy television display to a wider, movielike format, as well as doubling the vertical and horizontal resolution, enhanced the viewers' sense of reality. After a decade of work, Japanese companies began building prototype studio equipment for producing the improved pictures. U.S. filmmakers were enchanted. Not only could they use these tools to produce crisp images, those movies could then easily be converted into any one of the less demanding formats used to broadcast television worldwide.

Enthusiastically backed by U.S. broadcasting companies, Japanese engineers proposed their specifications for producing images as an international standard. Implicit in the proposal was a new market for high-definition cameras, videotape recorders and other editing equipment; new television receivers for consumers would not be far behind.

Industry pundits had already begun making mouth-watering predictions: HDTV equipment, they promised, would be a $100-billion-a-year worldwide industry by the year 2000. Others argued HDTV would spur a host of building-block technologies, such as microelectronics, and serve as a platform for hybrid computing-entertainment products. HDTV looked like a stairway to equipment makers' heaven.

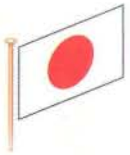
The Europeans were aghast. From their perspective, Europe's consumer electronics giants, particularly Philips and Thomson and even the German semiconductor maker Siemens, relied too heavily on consumer electronics sales to let Japanese manufacturers swamp their home markets just as the economic walls between European countries were crumbling. "We thought, 'Jesus, we'd better not fall into the trap of someone dictating what we should do in production and transmission,'" says Pieter W. Bögels, director of Philips Consumer Electronics and president of the Eureka HDTV campaign.

Transmission Standards

MAC

Multiplexed Analogue Components

Developed by companies throughout the European Community in the 1980s, MAC includes a family of enhanced (D2-MAC) and high-definition (HD-MAC) standards. HD-MAC, which will be broadcast from the Olympics, will deliver 1,250 lines at a rate of 50 frames per second.



MUSE

Multiple Sub-Nyquist Encoding

Work on MUSE began in Japan in the 1970s. Also a family of standards, high-definition MUSE delivers 1,125 lines at a rate of 60 frames per second. Japan began eight hours a day of MUSE broadcasts last November 25.

NTSC

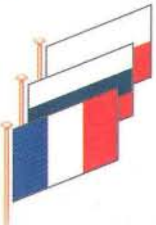
National Television Systems Committee

Developed in the U.S. and adopted in other countries, including Japan and Canada, NTSC offers viewers 525 lines at 60 frames per second. It was originally designed to transmit black-and-white images; color was added later. Regular broadcasts began in 1941 in the U.S.; color broadcasts were initiated in 1954.

PAL

Phase Alternation Line

This standard was developed in Europe and widely adopted as a 50-hertz alternative to the color NTSC signal. It delivers 625 lines at 50 frames per second. Regular broadcasts began in 1967. Transmissions of an enhanced, widescreen version, called PAL-plus, should begin in 1995.



SECAM

Système Électronique Couleur avec Mémoire

France developed SECAM in the 1960s as yet another color alternative to NTSC; it was also adopted by Russia and many eastern European countries. Like PAL, SECAM provides 625 lines at 50 frames per second. Regular broadcasts began in 1967.

In 1986 Europeans vetoed the proposed world standard and vowed to fight back. The objective was clear: cordon off the European markets from Japan's new television technologies until domestic manufacturers were ready with competitive products. To do this, European industrialists turned to the same tool that Japan had wielded: technical standards. "We had to ask the governments to act like the Japanese and create an environment that allows us to introduce a new television system in Europe," Bögels says.

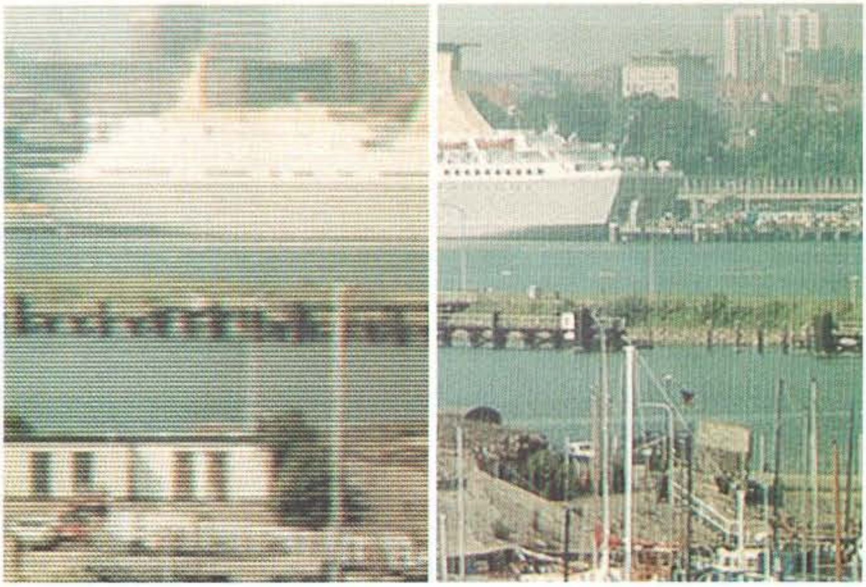
Industrialists at Philips and Thomson, with help from the French and German governments, drafted a plan for routing the Japanese producers from their home market. Under the Eureka umbrella, they pulled together some 30 research groups and companies that would share the "precompetitive" task of hashing out European standards for the production, transmission and reception of high-definition signals. Afterward manufacturers would build unique products based on those standards.

The European Commission, which initiates policies for the EC, also did not hesitate to take up the banner of competitiveness. In late 1985 the commission adopted an amendment, directly aimed at supporting industry. "Look, look here at Title VI," says Filippo Maria Pandolfi, the European commissioner for science and research, as he thumbs through his copy of the Single European Act. He points to a lead statement: "The Community's aim shall be to strengthen the scientific and technological basis of European industry and to encourage it to become more competitive at international level."

"This is our Bible," emphasizes Pandolfi, a lifelong politician who took up his post in Brussels three years ago, after stints as Italy's secretary of agriculture and secretary of finance. To promote European industry, the commission must take a firm hand in establishing enormous, high-profile projects focused on technologies deemed key to the competitiveness of European industry, Pandolfi declares.

Now, as Europe begins major demonstrations of its high-definition program, the costs of that endeavor are becoming clear. Japan continues to hold a commanding lead in the race to HDTV. Japanese engineers, too, will be sending home Olympic pictures in high definition. Broadcasters there, however, will be fitting the programs into the regularly scheduled eight hours a day of HDTV, which began last November. (Europe plans to begin commercial high-definition broadcasts in 1994.)

A weak domestic consumer electronics industry and a government that shies away from policies that smack of "picking winners and losers" conspired to make U.S. equipment makers the laggards on the HDTV curve. But now, with warm encouragement from the Federal Communications Commission (FCC), U.S. researchers have adopted a leapfrog strategy. Their plunge into the next generation of television technology—namely, all-digital systems—is causing tremors throughout Europe.



DOUBLING THE NUMBER OF LINES of a conventional European television picture (*left*) from 625 to 1,250 lines is one key to high-definition images (*right*).

Bandwidth Bottlenecks

The Europeans are no strangers to digital technologies. When the Japanese laid down their cards, engineers at Thomson's electronic imaging laboratory in Rennes were at the forefront of standardizing the digital techniques used in production studios. "When we began HDTV in Europe, there was a debate, in this lab in particular," recalls Robert Boyer, who manages the group: Should the researchers continue to explore digital techniques or follow a more evolutionary path?

By the late 1970s television production had become a hybrid of analog and digital signals. The images detected by a camera are analog by nature. But in most studios, engineers immediately transform those signals into digital ones because bits can be edited and manipulated with much more ease than waves can. Once producers are satisfied with the pictures, the bits are converted back into analog waves and transmitted according to the prevailing transmission standard.

Nevertheless, like most other teams in Europe, the researchers at Rennes, became swept up in the Eureka fever for launching an alternative to Japan's high-definition technology. At the time, Boyer insists, the advantages of an all-digital high-definition television system were still unclear. Without specialized electronics for modulating and compressing the data, digital signals threatened to chew up far more bandwidth than analog waves did.

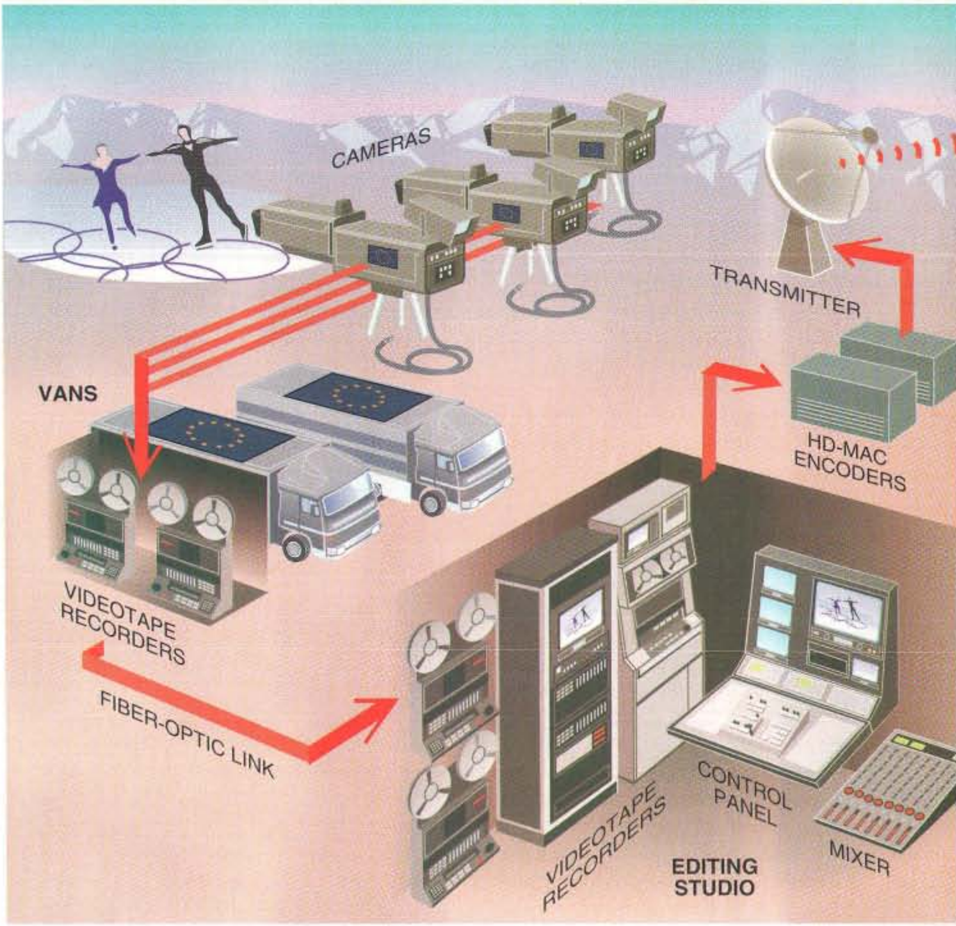
Finding space in the radio spectrum to send more signals has always been a problem. Most European television broadcasters squeeze signals into eight-megahertz windows; in Japan and the U.S., broadcasters make do with six-megahertz slots. "We didn't know how to get the wider signal to the consumer, so advanced television was a small effort at Philips," says Marcel J.J.C. Annegarn, who oversees Philips's visual communications department.

Japan's proposals for transmitting high-definition television, called MUSE, also ran up against a bandwidth problem. MUSE's high-resolution pictures pack about five times as much data as conventional images do. But by sending pictures from satellites directly to antennas atop consumers' homes, the Japanese could make use of 12-megahertz channels and so need less formidable compression techniques.

In return, the Japanese researchers sacrificed any hope that their data-heavy signals could be displayed on standard televisions. To begin with, they were abandoning any resemblance to existing transmission formats. To recreate pictures from the clues contained in the compressed signals, a re-

High-Definition Olympiad

Europe's high-definition broadcasts from the Olympics will rely on a battery of technology to record, edit, transmit and display sharp images. On the Olympic grounds, a fleet of vans carrying cameras and videotape recorders will capture live action. The images will be conveyed by fiber-optic cables to central editing studios. There, technicians will combine footage from different events, add interviews and other sequences and edit the programs. Those signals are then compressed by encoders and transmitted via satellites to dozens of viewing sites. In such halls or theaters, people can watch the sporting events on any one of a number of large (or smaller) screens. The broadcasts are funded by companies, national governments and the EC under a program called Vision 1250. There will be 50 viewing sites for the Winter Games and as many as 100 sites for the Summer Olympics.



ceiver would have to rely on complex signal processors and memory chips.

To fend off Japan's proposals, Europe needed a ready-made alternative, preferably one that seemed as different from MUSE as possible. Researchers at Britain's Independent Broadcasting Authority obliged. They had been working on a signal standard called MAC, which extended some of the philosophies of the digital studio to transmission.

Like Japan's MUSE signal, MAC relied on a compressed analog transmission signal, accompanied by digital sound and a supplementary digital stream of information that would tell a receiver how to reconstruct the picture. MAC would also have to be broadcast by satellite. (Cable offered adequate bandwidth for transmitting high-definition signals but was not used much in Europe.) Most critically, European planners insisted that MAC be compatible with conventional European transmission standards. All-digital systems were put on the shelf.

Hammering out the pan-European consensus needed at every step, however, proved anything but easy. Researchers at French and Dutch laboratories were better acquainted with investigators in the U.S. than they were with one another. Language barriers, traditional cultural ambiguities and distrust complicated communications. And although European laboratories had earned a reputation for extending the boundaries of science and technology through research, their work moved less swiftly into the marketplace.

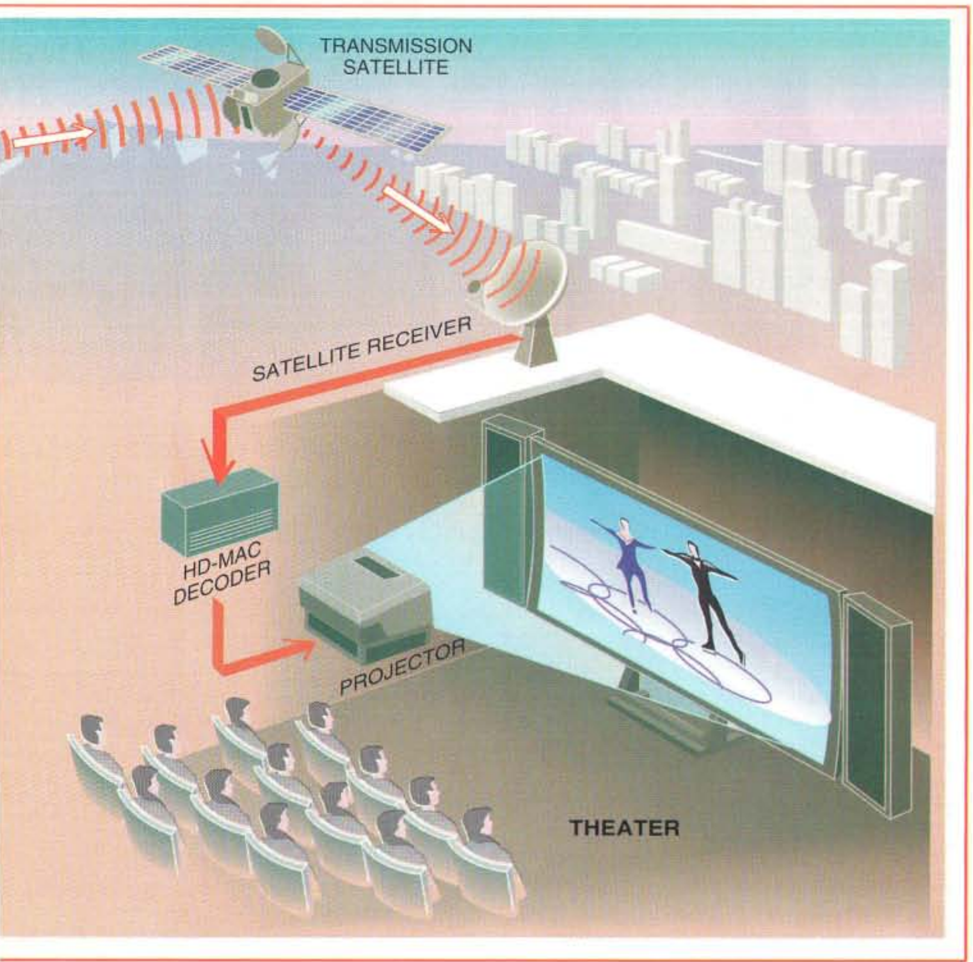
Compatibility Conundrums

Even more vexing than simply designing a transmission system is trying to smooth the transition from a deeply entrenched technology to a new one. Current European television transmissions convey 625-line pictures to consumers' homes, using one of two transmission standards, PAL or SECAM. The images are displayed at a rate of 50 frames a second. (Actually, the picture lines are "interlaced," meaning that alternating lines are shown at a rate of $^{1}/_{50}$ of a second; displaying the entire picture takes $^{1}/_{25}$ of a second.)

Broadcasters in the U.S. and Japan use a transmission format, known as NTSC, adopted in 1941. This offers 525-line images at a rate of 60 frames per second. When U.S. engineers began pushing for color television a decade or so later, they were instructed by the FCC to make the new signal compatible with the old. So they cleverly managed to slip a chrominance (color) signal into the luminance (brightness) signal. The new signal could be seen on either the old black-and-white or the new color sets. But the designers paid a penalty. Because the chrominance and luminance signals cannot be perfectly separated, the final pictures are often distorted.

Europe's color broadcasts are already of better quality than those in the U.S., largely because regulators made available more spectrum space for the enhanced signals. Although PAL and SECAM also transmit composite analog signals, the wider channel bandwidth meant engineers could separate chrominance and luminance signals more precisely. (The slower frame rate, however, creates a slight flicker on the screen.)

To remain compatible with Europe's existing television broadcasts, Eureka planners needed to adopt a signal that was principally analog. But rather than cobbling the chrominance and luminance signals into a composite wave, researchers planned to transmit them as separate components. In this way, MAC



promised to vanquish many of the artifacts in conventional broadcasts. Audio information and supplementary processing data would be sent digitally along with the principal MAC signal.

Eureka then tailored MAC to fit Europe. Whereas Japan's high-definition signal was designed to convey 1,125 lines at a scanning rate of 60 hertz, MAC would transmit 1,250 lines at Europe's 50-hertz rate. Still, beneath such differences, MAC and MUSE were siblings: both were analog technologies that doubled the vertical and horizontal resolution of their predecessors. And both would show wider pictures.

To send all those additional data, even in 12-megahertz satellite channels, engineers had to construct specialized techniques for modulating and compressing the signals. Like an egg slicer, modulation carves the analog waves that create images into slivers that are more easily transmitted. The more finely the modulation techniques shape the signals, the sharper the final image.

Just before transmission, the edited signal would be compressed—literally stripped of details that viewers would not miss. Engineers play several tricks to slim down the signal so it fits the bandwidth and yet does not look distorted on the screen. For example, static information in an image, such as an intricate wallpaper design, can be conveyed infrequently, letting the receiver draw on information stored in its memory. Pictures that move rapidly—say, a woman waving a scarf—must be updated more frequently but can be less detailed because the human eye cannot follow patterns that change rapidly. To portray intricately patterned objects that move slowly, engineers often supplement the usual signals with "motion vectors" that give the television receiver additional data.

MAC Muddles

Getting the various European nations to agree on a single MAC standard took time. Throughout the 1980s, a dozen or so variations, each with different features, were proposed and shot down. Eureka planners eventually settled on a two-step strategy: First, manufacturers would launch a precursor to high definition called D2-MAC, which would offer somewhat better images than conventional television does. D2-MAC 625-line pictures, backed by four digital sound channels, would deliver 16 by 9 images. After a few years, manufacturers would step up to true high definition, or HD-MAC technology. Consumers who bought D2-MAC setups would be able to see high-definition pictures, albeit with the resolution of D2-MAC—or they could buy an additional HD-MAC decoder.

Manufacturers argued this strategy gave them training wheels that would enable them to master advanced television. Yet to consumers and some broadcasters, the D2-MAC strategy looked bewilderingly complex and suspiciously like a plot to get them to start footing the high-definition development bill. Broadcasters worried they would have to buy several generations of studio equipment and encoders. Consumers wondered how many decoder boxes would end up in their living rooms.

Such objections began unraveling some of the loose edges of Eureka's neatly conceived project. When improvements in satellite technology outpaced the development of D2-MAC equipment, a handful of entrepreneurs, led by media tycoon Rupert Murdoch, began beaming conventional PAL signals to consumers instead of waiting for MAC. By last year these satellite owners had won more than three million subscribers and showed no inclination to quit. At the same time, terrestrial broadcasters, particularly in Germany, began worrying that satellite services would lure away their audiences. These broadcasters demanded a way to upgrade their transmissions.

Like a gambler at the roulette wheel who tries to improve the odds by putting down multiple bets, manufacturers obliged broadcasters' requests. They found a way to enhance the conventional signals and called this service PAL-plus. Like D2-MAC, it promised a sharper, wider (16:9) picture for those who bought a new PAL-plus set.

Because the demonstration pictures for PAL-plus look crisp, many in Europe have begun wondering whether consumers' interest in MAC will be washed out. Leaving "free-market forces" to sort out standards is simply "rubbish," insists Groenenboom of Philips. Still, equipment producers have hesitated to tool up large assembly lines for D2-MAC, fearing that consumers will not buy the products. The equipment manufacturers consequently tried to force the issue by asking the European Commission to lay down directives, or rules, requiring satellite broadcasts to conform with MAC standards.

For more than a year, Pandolfi, the European science commissioner, tried to chip away at this roadblock. Pandolfi has few qualms about trying to support high-tech companies, although he sometimes has trouble garnering support from Europe's other commissioners, many of whom are caught up in monetary and agricultural reform.

Pandolfi's solution was to draft a directive on satellite transmissions that would take effect on January 1, 1992. He hoped it would give manufacturers enough assurance about the future of MAC to produce more equipment—and broadcasters enough encouragement to embrace MAC. In December his efforts were close to yielding a small harvest: the Council of Ministers agreed that 16:9 transmissions must use D2-MAC; existing broadcasters who use PAL or SECAM must simultaneously use D2-MAC by 1995; and any high-definition service that is not "completely digital" must use HD-MAC. The EC may also subsidize D2-MAC broadcasts, although Germany has protested.

In the future, Pandolfi argues, the commission must work harder to spur product development. And the products he has singled out are important parts of the HDTV scheme: display screens and semiconductor chips.

Yet, like the equipment manufacturers, Europe's chip makers say they have not been waiting for technical direction as much as for a political sign that their investments in designing such chips will not be wasted. Since 1985 the semicon-

Can the U.S. Leap Ahead in Digital Television?

As Europe was organizing its high-definition television program in the 1980s and Japanese companies were building prototypes, the U.S. waffled. Companies battered by Japanese competition were reluctant to venture back into the consumer electronics arena. The government refused to play a role in promoting what it deemed was a commercial technology.

The decision may have been a wise one. Now the U.S. is rapidly moving into digital television technology, a jump ahead of the HDTV approaches endorsed by Europe and Japan. The Federal Communications Commission (FCC) has pledged to select a new standard for television broadcasting sometime in mid-1993. Of the six proposals the agency is considering, four promise to transmit pictures as streams of digital bits rather than as traditional analog waves.

The FCC began nudging developers toward the digital domain when it laid down the rules for the next generation of U.S. television technologies. Future broadcasts, the agency decided, must offer significantly better pictures than the present NTSC transmission standard does, yet they must fit into the same six-megahertz channel and not muddy other existing broadcasts.

Such requirements left engineers only a few options. For instance, the broadcast slots most likely available seemed to be the so-called taboo channels that previous spectrum planners had left vacant to avoid signal interference. By sending streams of bits rather than waves, researchers reckoned they could use those channels.

Transmitting signals digitally promised other benefits, too. Such pictures look equally clear to all viewers who can receive them. Analog signals, in contrast, degrade gracefully, giving viewers on the edge of a broadcasting footprint increasingly fuzzier pictures. (The downside: add too much noise to a digital signal, and viewers see nothing.) Digital systems should also make way for a change in programs. Broadcasters may be able to deliver interactive programs to viewers, who in turn could manipulate the images.

Enthusiasm for digital systems blossomed about 18 months ago, when engineers at the Videocipher division of General Instrument in San Diego said they could compress digital signals into six-megahertz channels. Soon afterward, three other research teams declared they, too, had digital solutions.

Each proposal makes different trade-offs among such factors as the distance signals will travel, error-correction codes accompanying the signals and the power needed to transmit, says William Hassinger, an assistant bureau chief at the FCC. Over the next year, the digital proposals (along with two contending analog bids) will run through a gauntlet of tests at the Advanced Television Test Center, an industry-financed laboratory in Alexandria, Va. After scrutinizing the test data, the FCC will pick the system that consistently offers the best-quality picture.

That decision, however, will be just one more episode in the saga of HDTV in America. Next, companies have to design products around those codes. As of late December, only General Instrument had demonstrated prototype hardware for encoding and decoding digital signals. The equipment consisted of two boxes the size of refrigerators—hardly the few chips that will be needed before they are ready for store shelves. Consumers are unlikely to see new televisions before 1996, experts say. Precisely how much U.S. firms will benefit from a domestic standard will depend on their ability to build hardware.

Even the future of terrestrial broadcasting is in question. "We'll see a huge shift of technology in the 1990s," Hassinger predicts. All telecommunications, notably television, radio and mobile telephones, will be delivered digitally, he says. And many groups other than traditional broadcasters—cable television providers, direct-broadcast satellite owners and regional telephone companies among them—are already investigating how they might take part in this new digital age. "It's going to be confusing," Hassinger promises. "Everyone will be doing everything."

Contending Television Formats

GROUP	TYPE	LINES PER PICTURE	TEST PERIOD
Sarnoff/ Philips/ Thomson/NBC	Analog	525	Finished
NHK	Analog	1,125	Finished
General Instrument/M.I.T.	Digital	1,050	Dec. 91–Jan. 92
Zenith Electronics/ AT&T	Digital	787.5	Feb. 92–March 92
Sarnoff/ Philips/ Thomson/NBC	Digital	1,050	April 92–May 92
M.I.T./General Instrument	Digital	787.5	June 92–July 92

ductor industry has sponsored its own joint research projects—first the Megaproject and now JESSI. As a result, says Horst Fischer, chief operating officer of Siemens semiconductor group in Munich, the memory technology for storing signals and the digital signal-processor designs needed for television decoders are both in hand.

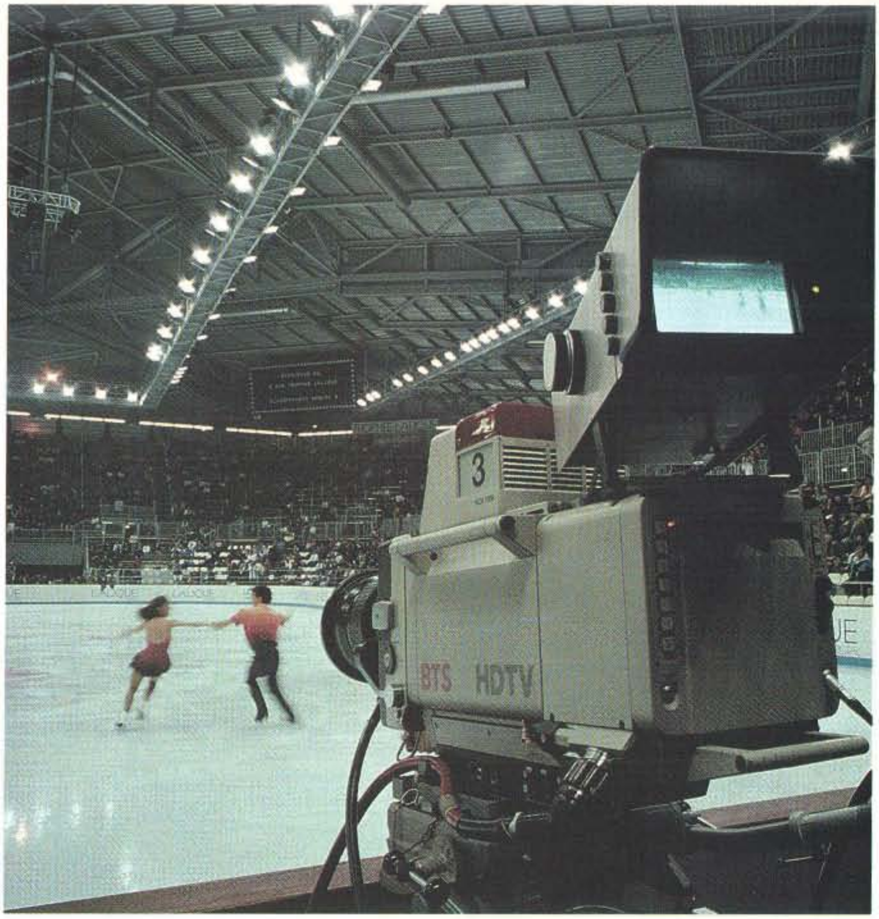
"For us, the critical situation is the uncertainty of the standards," Fischer says. "To develop such chip sets, you are talking a high, two-digit-million-deutschemark figure in design cost—and hundreds of man-years." Until he is convinced that manufacturers will go ahead with their MAC plans, he is reluctant to set engineers to the task of turning MAC algorithms into silicon processors.

Fischer is particularly wary because of the current precarious state of the European microelectronics industry. Even though parent company Siemens was profitable last year, the semiconductor division was in the red. Others are in worse shape. Just off Philips's main grounds in the village of Nijmegen sits a still new fabrication facility, which was designed to churn out state-of-the-art static random-access memories (SRAMs). Then the company decided not to build SRAMs after all. "Philips considers the Megaproject successful because we met the goal of becoming owners of the technology," a company representative explains. "The only thing we didn't do was start mass production."

Siemens, too, has had its share of disappointments. For the past five years, its engineers have devoted much time to designing chips for a highly digital (but not high-definition) television. "It has a lot of very nice features," Fischer says, including a flicker-free, 100-hertz picture. "But the customer won't buy it. The customer is not willing to pay 1,000 DM for this type of box," he says with a halfhearted laugh.

Fischer worries that MAC could suffer a similar fate. Even a "perfect technical solution" is hard-pressed to beat a competing approach that is better marketed, he points out. Should the first generation of MAC products meet with a chilly reception from consumers, chip makers will be confronted by huge embedded costs and shallow market penetration. That will leave them little choice but to embark on costly redesigns of the components, hoping that cheaper and more powerful technology will gain a toehold.

Such a path spells almost certain financial losses. And at that point, "no matter how good your people are, your technology is worth nothing because you have no return on your investment," Fischer concludes. As a result, Siemens continues to wait for a propitious sign.



MORE THAN 40 HIGH-DEFINITION CAMERAS, designed under Europe's Eureka program, will be used to tape action at this year's Winter Olympics.

From the consumers' viewpoint, what would likely be the most noticeable element of new high-definition television has been perhaps the one most neglected by manufacturers—namely, the development of flat video panels more than a meter in diameter for carrying the high-definition pictures.

Flat Horizons

Building such screens means abandoning the classic cathode-ray tubes for a more novel approach. A host of imaginative solutions exist. Yet many display experts believe the large-screen technology nearest to hand will be projectors based on liquid-crystal technology. Liquid crystals are curious half-breeds, neither fully liquid nor crystal, that change their orientation—and their ability to guide polarized light—when exposed to an electric field. By sandwiching such materials between glass sheets, researchers can build high-resolution displays similar to those in laptop computers. Active-matrix displays include lithographically patterned circuits.

Still, manufacturing active-matrix liquid-crystal displays has proved to be excruciatingly difficult—and costly—even for Japan's semiconductor giants. (Japan has committed in excess of $2 billion in liquid-crystal display technology and still suffers from low yields.) Even projection displays, which use much smaller liquid-crystal elements as light modulators, have proved finicky. As a result, European and U.S. companies have been skittish about plunging into flat-panel screen assembly.

Europe may hold one card in the liquid-crystal business, however. For 160 years, E. Merck has had its headquarters and main research laboratory in the small town of Darmstadt, south of Frankfurt. The research laboratory boasts the world's largest collection of liquid-crystal compounds—more than 5,000 different substances. Merck's computerized data base of these compounds, along with experimental results on thousands of liquid-crystal mixtures, means that much primary design can be executed on computers these days.

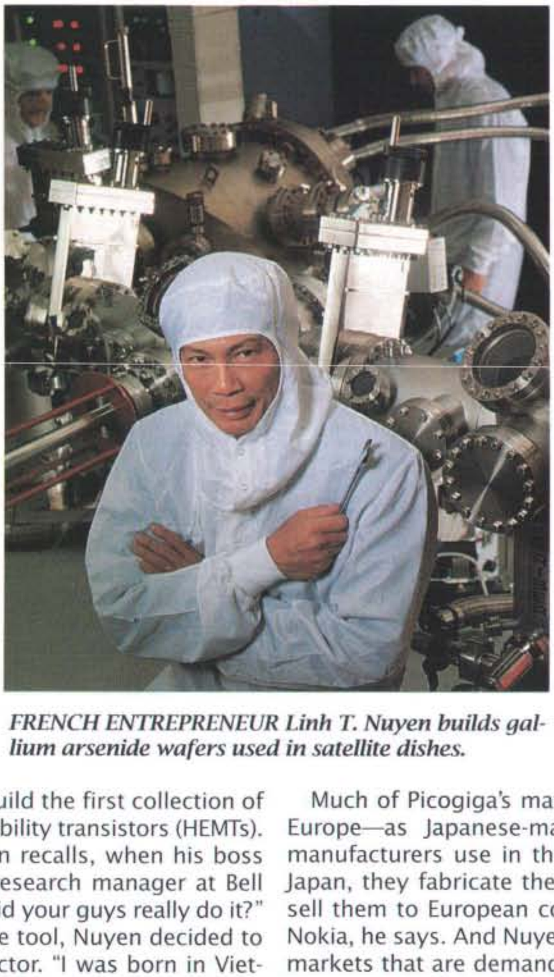
Although Merck executives confide that they would like to help jump-start Europe's efforts in flat-panel screens, the company's best clients are in the Far

Building up Business, Atom by Atom

On the southern fringe of Paris, a tiny company called Picogiga is churning out materials that are likely to wind up at the heart of almost a third of the home satellite receivers in Europe as well as in Japan. But before these specialty semiconductor materials rest on European shores, they must first travel by way of Japan.

Almost six years ago Linh T. Nuyen, then head of a research group at Thomson CSF's laboratory in Orsay, did the unthinkable for a French researcher: he quit his job and opened his own company a few miles away in Les Ulis. "I was very naive," he says with a laugh. "But if you're very clearheaded, you don't take any risks."

Unlike the U.S., where forming a company is almost as much a part of the national identity as is baseball, Europe has few start-ups. Until the early 1980s, many nations' tax laws treated small enterprises harshly. Ironically, it was under the early tenure of socialist president François Mitterrand that France began to bend those rules to accommodate entrepreneurial high-technology ventures.



FRENCH ENTREPRENEUR Linh T. Nuyen builds gallium arsenide wafers used in satellite dishes.

At the time, Nuyen was exploring ways to build exotic semiconductor structures with a team of Thomson researchers. He was particularly intrigued by a technique invented at AT&T Bell Laboratories for manipulating thin layers of atoms, called molecular-beam epitaxy (MBE). At the heart of an MBE machine is a very high vacuum chamber; researchers place a substrate in this chamber and deposit atoms of different materials on top of the wafer. In this way, they can artificially grow materials with layers of different materials no more than a few atoms thick.

By carefully tweaking the crystal structure of the materials, Nuyen's team managed to build the first collection of blisteringly fast high-electron-mobility transistors (HEMTs). The victory was clinched, Nuyen recalls, when his boss got a transatlantic call from a research manager at Bell Labs who asked, with dismay, "Did your guys really do it?"

Confident he had mastered the tool, Nuyen decided to make the leap to the private sector. "I was born in Vietnam," he says, "and a lot of my brothers and sisters left in 1975 and started businesses elsewhere." Linh was younger and so ended up in school in France. But he, too, had inherited a "more aggressive mentality—I liked to promote things."

Still, the first step was to ask Thomson CSF's chief executive to bless a new enterprise that would be devoted to making gallium arsenide substrates for very fast transistors and lasers. "The French way is different than the American," Nuyen says. "You just can't disappear in France. The industry, the country, is too small." Besides, no one had ever before left Thomson CSF to launch a start-up.

After 18 months, Nuyen and colleague Jean François Rochette (also formerly with Thomson) secured enough money to buy an MBE machine and hire a few technicians. They had also found their first client—in Japan. At the time, Japanese manufacturers were designing the country's high-definition television system, which would be based on direct-broadcast satellites. Nuyen realized that the acute sensitivity of gallium arsenide transistors could translate into highly sensitive—and compact—microwave antennas. "The Japanese asked me so many questions," he recalls. But eventually they were convinced.

Today Nuyen's four MBE machines and team of 39 people work three shifts to put out about 10,000 specially doped, or charged, gallium arsenide wafers a year. The quality of their materials is high—fewer than 10 defects per square centimeter on average. Every year they have nudged their standards a little higher, balancing the number of defects against the number of wafers they must scrap. "A 75 percent yield is fine in terms of our finances," Nuyen says. "We'd prefer 95 percent, but then our standards would be less severe."

Wooing European customers is still tough, he concedes. Established European manufacturers traditionally dislike relying on start-ups for fear they might suddenly fold. What is more, the number of European microelectronics makers plunging ahead in specialty materials like gallium arsenide is still limited. Nuyen worries about moves to consolidate Europe's microelectronics industry further. "In Japan, the companies are like tigers trying to eat one another," he says. "Our semiconductor industry will be destroyed by defensiveness."

Much of Picogiga's materials do nonetheless return to Europe—as Japanese-made transistors that European manufacturers use in their satellite dishes. "We ship to Japan, they fabricate the transistors and receivers, then sell them to European companies" such as Marconi and Nokia, he says. And Nuyen has his eye on other emerging markets that are demanding lighter, more compact electronics. Portable telephones are one potentially lucrative application, he notes.

In hopes of expanding his business, Nuyen has begun searching for another round of venture-capital money. This time he is hoping to start up a second plant in the U.S. or Japan. He has long favored the U.S. When Nuyen started Picogiga six years ago, he found more money but a tougher environment in the New World. "They told me, 'You will fail because you don't understand American laws or lawyers,'" he recalls. This time he plans to keep his eye trained on his customers.

East. Merck has resolutely decided not to compete with its customers by moving beyond materials into display-system production. "For our commercial success, it's not so important if Europe sets up a project or not," says Georg Weber, who heads the physical research department for liquid crystals at Merck. "We're involved anyway—we have a strong involvement with Japan."

The best opportunity Weber could foresee in Europe would be another massive project funded by national governments, the European Commission and corporations. "It's a question of whether these products are considered strategic components," he says.

At the end of 1991, Philips indicated it would build a factory in Eindhoven for making active-matrix liquid-crystal displays. And rumblings from the European Commission seemed to favor some kind of display project. Given U.S. companies' interest in displays but inability to fund a large-scale plant, some observers suggest that such an operation might become a joint Europe-U.S. initiative. "Such a flagship project would be a political decision, like Airbus," Weber points out. He pauses. "It's a nice plane, but it costs the taxpayers a lot of money."

Digital Dilemmas

Perhaps the twist of events that worries European industrialists most is that their work may be swept aside by the very technology that was a strategic sacrifice for MAC—namely, digital television. All-digital television implies that in the interval between when a camera records a live image and a screen displays the final picture, the video and audio information is expressed in digital form. Digital television is "high definition" only if it provides double the vertical and horizontal resolution of conventional images.

Because European industry has spent so much time supporting the MAC initiative, few are yet willing to break ranks with MAC publicly. But a subtle word change is helping unleash research on digital systems, which offer a way to overcome the historic frame-rate differences and promise to tie video systems more closely to other technologies such as telecommunications and multimedia computing.

At a standards meeting in late November in Geneva, enthusiasm for digital systems "was galloping madly" through the community, says Kenneth P. Davies, who directs standards and technology development at the Canadian Broadcasting Corporation in Montreal. The change: instead of discussing "digital HDTV," researchers are simply talking about "digital television."

The international technical community is already preparing for a digital future. At this year's World Administration Radio Conference, which meets in Spain this month, engineers will be angling to convince the technical body to reserve a frequency band for digital television. In the U.K., the British Broadcasting Corporation (BBC) has already added digital sound to many television programs.

Meanwhile the European research groups that contributed to the development of MAC have quietly returned to working on digital systems. "We are supporting the Eureka strategy on MAC," confides Maurizio Ardito, a senior researcher at the research center of Radiotelevisione Italiana (RAI). "But from a technical viewpoint, we are very sure that the future is digital."

For the past few years, RAI engineers in Torino, Italy, have been testing digital transmission schemes. Two years ago they showed they could send crisp digital signals between transmitting stations. Now RAI and BBC investigators are helping lead a new joint European research project to accelerate work on digital transmission. "Once MAC is adopted, we believe digital must be considered," Ardito says. BBC researchers hope Europe's generation of digital television will be ready by 1997.

Sweden's Sveriges Television in Stockholm is more impatient—particularly for a digital terrestrial service. "We don't think HDTV will be a success with the receivers today costing a fortune," declares Sven-Olof Ekholm, vice president of engineering. (Moreover, Sweden's broadcasters rely more on cable and terrestrial networks than on satellites.) "As we see it, we can use the time to make a system more fitting to the next decade," Ekholm adds. By next year his researchers hope to demonstrate algorithms for transmitting digital signals terrestrially.

Not yet part of the EC, the Swedish researchers acknowledge they have been on the fringe of Europe's main research efforts on advanced television. They nonetheless suggest that they have stayed aloof from the political wrangling over HDTV. The MAC affair "has been the fourth crusade," Ekholm observes. "But this time, instead of the Muslims, it's the Japanese."

In spite of the growing interest, Jacques Sabatier, Thomson's senior vice president for business development in consumer electronics, dismisses the challenge from digital systems. "It becomes a simple issue if you are interested in the economics," he insists. "On a scientific basis, you can discuss different standards for years and years. It's always a long way between the first breadboard in the lab and the first day you can invent and implement."

For better or worse, Europe has a nascent HDTV system in place. After six years, Thomson and other companies are offering advanced—but not yet high-definition—television equipment. For instance, for about $7,000, consumers can buy Thomson's "Space System," which can display D2-MAC and PAL signals as well as the HD-MAC Olympic broadcasts (but with D2-MAC quality) on a 93-centimeter cathode-ray tube. Philips and others unveiled D2-MAC products last year. And although both Thomson and Philips are making prototype HD-MAC equipment for the Olympic viewing sites, consumers will not find that technology on the shelf for another year or two.

Even if those products fail to move off the shelves, Eureka has succeeded in buying Europe time to develop alternatives to Japan's high-definition technologies. It pulled engineers and executives from throughout Europe into an unprecedented joint development venture.

But the effort has had high costs. Although MAC promised European producers a slight edge in building hardware for their domestic consumers, it also cut them out of competing in markets outside Europe. And because MAC, like MUSE, is an analog transmission system, it provides no new technological directions. Digital links, in contrast, promise to tie together a diverse collection of technologies.

Europe's high-tech broadcasts may provide some of the sharpest pictures of the 1992 Olympic Games. Yet at the same time European companies will have to show that their six-year regimen has prepared them to make the leap into the fiercely competitive arena of high technology.

FURTHER READING

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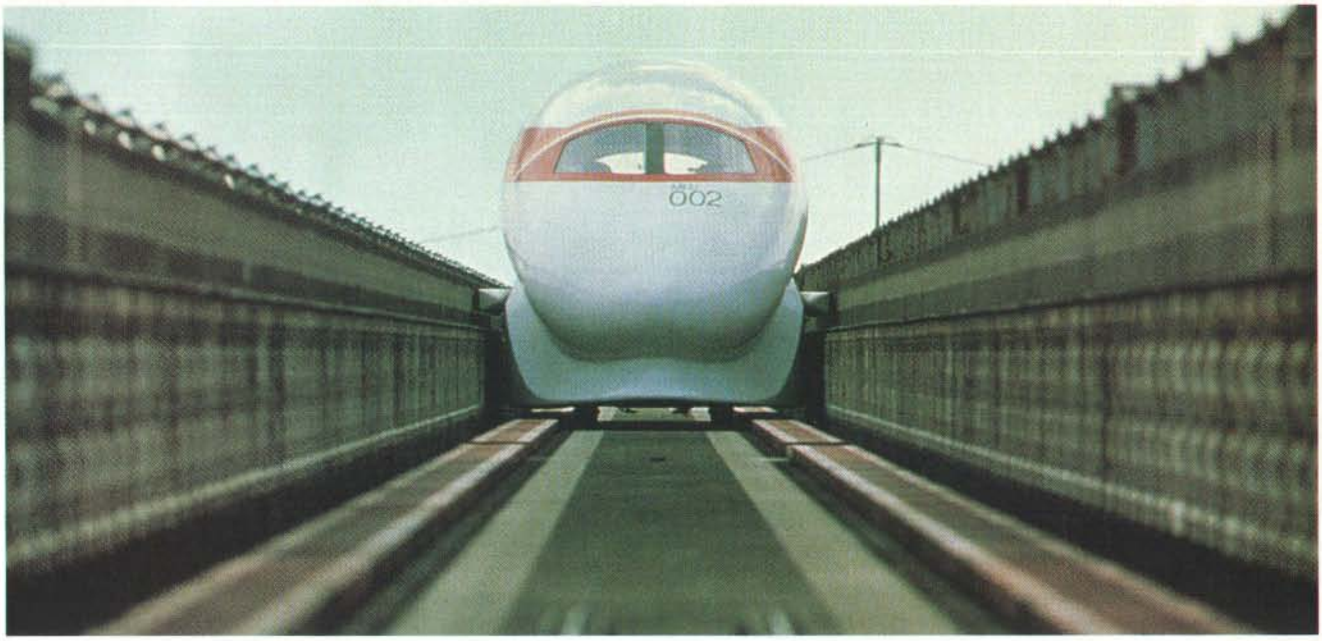
SCIENCE AND BUSINESS



MAGNETICALLY LEVITATED VEHICLE at a Japanese test facility. Photo: T. Matsumoto/Sygma.

Riding on Air

Congress votes to put maglevs back on track

Mary E. Hurley, the mayor of Springfield, Mass., would like to make her city a bedroom suburb of Boston. If she has her way, the 80-mile commute would take a mere 25 minutes on a sleek, streamlined train that would make the trip at more than 180 miles per hour. "This is an economic development tool the likes of which we haven't seen since the steam engine was invented," Hurley commented at a conference on high-speed trains last fall in Albany, N.Y.

Whether levitated and propelled above a guideway using powerful magnets, as in the maglevs of Germany and Japan, or running on conventional steel wheels like the Train à Grande Vitesse (TGV) in France, high-speed rail transit is gaining attention as a nonpolluting, energy-efficient technology that could eliminate congestion on the nation's highways and around airports.

Private developers and state governments already have more than a dozen projects on the drawing board. One would use a German maglev to connect the airport in Orlando, Fla., with Walt Disney World and other area resorts, while developers in Texas are pushing a proposal to link major cities using French TGV technology.

Even so, the mayor from Massachusetts and latter-day Cornelius Vanderbilts will need a lot of help from deficit-burdened legislators in Washington. "As you well know, the big problem in all of this is money," said Senator Ernest F. Hollings of South Carolina at a meeting of a high-speed-train trade group last fall.

The idea of Springfield as a commuter stop of Boston may now be a little less farfetched. Enthusiasts of high-speed rail received an astonishingly large Thanksgiving present from Congress as part of the $151-billion surface transportation bill, which President George Bush was expected to sign sometime in mid-December. Tucked away among the billions in new spending for tired roads and bridges was $725 million to develop and build a prototype for a true red-white-and-blue, American-designed maglev by the end of the decade. Moreover, the program is structured to attract private investment—$250 million by some estimates.

Congressional staff members attribute the size of the maglev funding to the advocacy of Senator Daniel Patrick Moynihan of New York, who has argued that the legislation would give the U.S. a last-ditch chance to prevent yet another domestically nurtured technology from being ceded to foreign competitors. The measure escalates an existing program, the National Maglev Initiative, from a cautious $20 million a year under the aegis of the Federal Railroad Administration (FRA) and the U.S. Army Corps of Engineers into a full-steam-ahead attempt to revive maglev technology.

A superconducting maglev was first proposed by U.S. engineers about 25 years ago. But development here has been mostly dormant since the mid-1970s. Japan and Germany now have an undeniable lead in maglev, both countries having produced working test models after investing more than $1 billion apiece on development with a heavy infusion of public funds. Nevertheless, Moynihan and others believe maglevs are a technology so immature that the U.S. can still catch up.

Before the U.S. does so, questions about maglevs' safety, economics and environmental impact would need to be addressed. Prospective regulators of these trains, which may streak along on elevated guideways at speeds of up to 300 miles per hour or more, wonder about the effects of electromagnetic fields from some designs on both passengers and the sensitive electronic systems of automobiles on nearby highways. Safety concerns intensified in October 1991, when an experimental maglev in Japan caught fire and was destroyed on a four-mile test guideway.

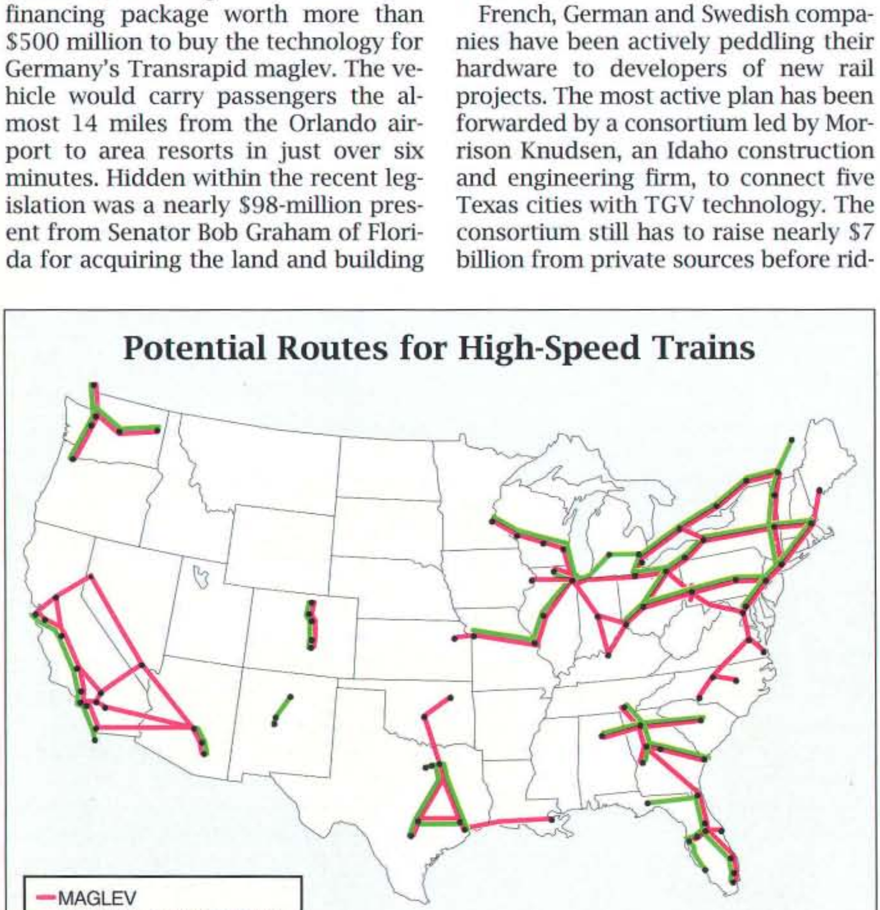
Among those watching the transportation bill wend its way through Congress were a roster of engineering firms, which included defense contractors, such as Grumman, that could benefit from a peacetime public works program. Also on the sidelines were some of the original U.S. maglev designers, whose ideas have been simmering all these years. It is their designs and newer work that will challenge the Germans and the Japanese, perhaps with improved superconducting technology, such as cheaper and better cryogenic systems for cooling the magnets.

Although Moynihan's plan calls for a maglev designed and produced in America, the world's first commercial high-speed maglev is expected to begin operation in Florida in 1995—using nonsuperconducting German technology. Maglev Transit, which is organizing a group of Japanese, German and U.S. investors, has begun to assemble a financing package worth more than $500 million to buy the technology for Germany's Transrapid maglev. The vehicle would carry passengers the almost 14 miles from the Orlando airport to area resorts in just over six minutes. Hidden within the recent legislation was a nearly $98-million present from Senator Bob Graham of Florida for acquiring the land and building the elevated guideways for this project.

The mammoth transportation bill was less generous to backers of other forms of high-speed rail technology. Dropped from the final bill was a provision that would have allowed states to use a portion of their billions in highway money for intercity rail projects.

Not everyone agrees with the decision, which stemmed, in part, from a jurisdictional dispute between committees in the House of Representatives. Ross Capon, executive director for the National Association of Railroad Passengers, a Washington, D.C.–based public interest and lobbying organization, says the bill's emphasis on fostering maglev ignores more practicable near-term solutions: TGV technology or upgrading existing Amtrak routes. The TGV and other electrically driven high-speed trains reach speeds nearing 200 miles per hour on high-quality, conventional steel track. Their wind tunnel-tested aerodynamic design, computerized control, and sometimes pressurized carriages give them a marked resemblance to a modern airliner. The Japanese Shinkansen had its first run in the mid-1960s—and hundreds of millions have ridden in a bullet train since then.

French, German and Swedish companies have been actively peddling their hardware to developers of new rail projects. The most active plan has been forwarded by a consortium led by Morrison Knudsen, an Idaho construction and engineering firm, to connect five Texas cities with TGV technology. The consortium still has to raise nearly $7 billion from private sources before rid-



Potential Routes for High-Speed Trains

SOURCE: High Speed Rail Association

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ers rocket across the prairie at speeds approaching 200 miles per hour. While Morrison Knudsen assured the state of Texas it does not need state money to finance the project, company officials are counting on bonds that are exempt from federal tax for about $2.5 billion of the total package.

The Texas project, which has faced stiff opposition from Southwest Airlines, a regional air carrier, might also be eligible for some of the $1 billion in federal loan guarantees for nonmaglev high-speed rail projects, which were authorized by the bill. But appropriating the money to cover the loan guarantees could face an uphill battle in Congress.

There were other morsels for high-speed rail within the six-year transportation bill: a $50-million technology demonstration program and $25 million for research and development, money that can be used for either a maglev or a bullet train. The legislation also allows states to let developers of high-speed railways use land adjoining interstate highways free of charge. And federal highway money can pay for altering highways for such projects.

If fast trains of any variety are to succeed in the U.S., the federal government must be prepared to reach into the public coffers again and again. Despite the contribution toward a maglev prototype, the bulk of expenditures for maglev will go toward building guideways. Those costs could range from $8 million to more than $60 million a mile, various studies show. There is little likelihood that any such venture could be self-financing, according to recent reports by the congressional Office of Technology Assessment and the National Research Council.

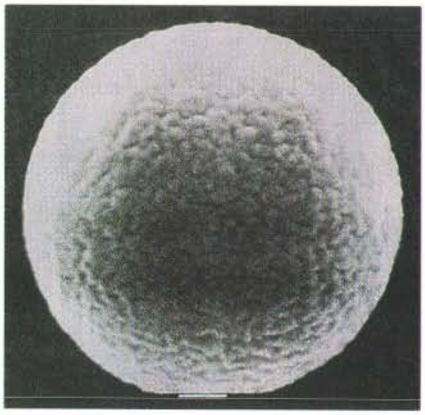
Still uncertain is the commitment of the government to high-speed rail. By its actions so far, the Bush administration has not been viewed as a great friend of passenger railroads. In its first two budget years the administration requested no funding for Amtrak.

FRA administrator Gilbert E. Carmichael maintains that the executive branch has been slowly warming to the need for upgrading passenger rails. "There's been a 180-degree turn in the past two years," Carmichael says, pointing to the new willingness by the administration to provide some funding for Amtrak's capital and operating budgets this fiscal year and its tentative support for high-speed rail projects. Hard choices by both the administration and Congress may determine whether a high-speed train ride will remain an experience U.S. tourists will only recount to relatives on returning from trips to Europe and Japan. *—Gary Stix*

It's a Wrap

Tiny spheres may make oral delivery of proteins a reality

Grilled salmon, T-bone steaks and Texas barbecue are no problem for the average stomach. Neither are such clinically important proteins as insulin, growth factors and blood cell stimulators. Digestion efficiently transforms these agents into fragments that are medically useless. Consequently, patients taking such drugs must put up with awkward, painful injections into veins or muscle or under the skin.



MICROSPHERES encapsulate and release drugs in response to changing acidity.

A way to deliver digestible proteins orally may finally be at hand. Clinical Technologies Associates (CTA), a small biotechnology company in Elmsford, N.Y., says it has found a way to shield proteins and other nonorally available compounds from the digestive tract and release them only after they have safely passed into the bloodstream.

The key is a process for making capsules of amino acids, the basic building blocks of proteins, that open in response to changes in acidity. CTA links the amino acids together into what it calls "proteinoids," an unusual branching configuration that allows them to join together and escape degradation, explains Michael M. Goldberg, CTA's president and chief executive officer. "The spheres protect the drug from the harsh environment of the intestine but are small enough to move across the mucosal barrier," he says.

To encapsulate a drug, CTA dissolves proteinoids in water and mixes the solution with a therapeutically desirable protein dissolved in low-pH solution, typically citric or acetic acid. The sudden acidity causes the proteinoids to aggregate into hollow spheres about the size of a red blood cell, thus encapsulating some of the dissolved drug. The capsules remain closed in the acidic environment of the stomach. But when they enter the bloodstream, the higher pH causes the proteinoids to come apart, allowing the contents to escape.

The company has been able to make microspheres of varying pH sensitivity and size. According to Goldberg, the substances have successfully encapsulated more than 10 different agents of widely varying molecular weights, from the small neurotransmitter dopamine, weighing in at 150 daltons, to insulin at 6,000 daltons and even a proprietary vaccine that weighs a whopping 2.5 million daltons.

The mechanism by which proteinoids transport drugs across the gut wall into the bloodstream is unknown, but that does not trouble Goldberg. "In the meantime, I have a phenomenon that's been proven to work in five different mammals," he declares. "We should see results at least as good in humans, if not better."

Several drug companies seem willing to find out if Goldberg is right. "The results CTA has provided on a number of proteins, including insulin and heparin [an anticoagulant], are really rather persuasive," comments Peter J. L. Daniels, a licensing director for the Upjohn Company in Kalamazoo, Mich. For now, Daniels prefers to keep confidential details of the company's partnership on a product widely believed to be insulin. Other pharmaceutical companies collaborating with CTA, including Genetics Institute, Inc., Sandoz and Tredegar Industries, are also playing their cards close to the vest. CTA plans to begin human trials for encapsulated heparin on its own within this year.

There is no shortage of candidates for encapsulation. Needles are still the only means of delivering the 16 proteins already approved by the Food and Drug Administration; the same limitation affects 120 other drugs awaiting review. Chronic diseases treated with routine injections and infusions of proteins, such as diabetes or the anemia caused by kidney dialysis, would offer multibillion-dollar markets if the drugs used to treat them, such as insulin and erythropoietin, were available in oral form.

If CTA's data bear out, Goldberg hopes a small family of proteinoid formulations will be able to deliver orally almost any useful protein. Biotechnology continues to unveil a plethora of interesting substances that mediate inflammation, repair bones and stimulate cells. Soon CTA may be able to call it all a wrap. *—Deborah Erickson*

Making Antisense

Drugs that turn off genes are entering human tests

The first medicines made by the biotechnology industry were copies of biologically active proteins found in the body that could be used to correct deficiencies or stimulate biological processes. The next generation of drugs promises to be even more potent. "Antisense" compounds now in development may have the power to block the expression of particular genes. Because many illnesses are caused when genes are expressed inappropriately—cancer and inherited and infectious diseases—proponents reckon the markets for antisense therapies in the tens of billions of dollars.

The first tests of such projections may not be long in coming. The Food and Drug Administration recently gave a provisional approval for the first clinical trial of an antisense product, a therapy for chronic myelogenous leukemia (CML). Tests on patients of the drug, produced by Genta in San Diego, are expected to start in 1992. The drug inhibits the proliferation of cells that have the "Philadelphia translocation," the chromosomal mutation that causes CML. Tests of other products are likely to follow soon.

Antisense compounds are short segments of single-strand DNA that bind to nucleic acids using the same complementary base-pairing mechanism that zips together two strands of natural DNA. The favorite target for antisense molecules is messenger RNA, which carries information from genes to the sites in the cell where a protein is made. An antisense molecule with a base sequence complementary to messenger RNA will bind to it, thereby preventing the cell from producing a specific protein.

Although natural DNA can be used as an antisense agent, commercial interest focuses on synthetic DNA analogues that replace the molecule's phosphate backbone with something more resistant to marauding enzymes that could destroy the drug. Of the many chemical backbones that have been investigated, two types appear most promising: methylphosphonates, pioneered by Paul O. P. Ts'o, a biochemist at Johns Hopkins University, and phosphorothioates, developed in large part by Jack S. Cohen, a researcher at Georgetown University. The merits of each approach are hotly debated by those in the field.

Genta's CML product, a methylphos-

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phonate, is already being tested in human cells from CML patients; during 1992, the company expects final approval to introduce the treated cells into patients. Ts'o, who holds patents on the chemicals, is a director of Genta and licenses the technology to the company. Initially the drug will be used in combination with autologous bone marrow transplantation. Bone marrow cells removed from selected CML patients will be treated with the antisense compound in an effort to eliminate leukemic cells. In the meantime, any cells remaining in the patients' bone marrow will be killed through radiation and chemotherapy. Then the healthy, cultured cells will be returned to the patients.

New techniques will enable investigators to monitor the numbers of healthy and leukemic cells in the cultures during the treatment. "We're still fine-tuning this," says Albert Deisseroth of M. D. Anderson Cancer Center in Houston, where the first patients will be treated. If the trial is successful, Genta will ask the FDA for permission to introduce the product directly into patients.

Ts'o is an unabashed booster of methylphosphonates. "They are the best," he says. Ts'o points to recent experiments by Esther Chang of the Uniformed Services University of the Health Sciences and others demonstrating that in tissue culture an antisense methylphosphonate could specifically block the mutated—and hence dangerous—form of an important human oncogene. Genta is hoping to develop products to exploit that effect.

But Ts'o's contention that his approach is superior to phosphorothioates is emphatically denied by Stanley T. Crooke, chairman of Isis Pharmaceuticals in Carlsbad, Calif., which has several antisense compounds under development. Crooke says Isis expected to ask the FDA by the end of 1991 for permission to conduct a trial of a phosphorothioate to combat papillomavirus, which causes genital warts. He also says Isis has used a phosphorothioate to cure a herpesvirus eye disease in mouse experiments, although he admits the test did not use a sequence of random bases as a control.

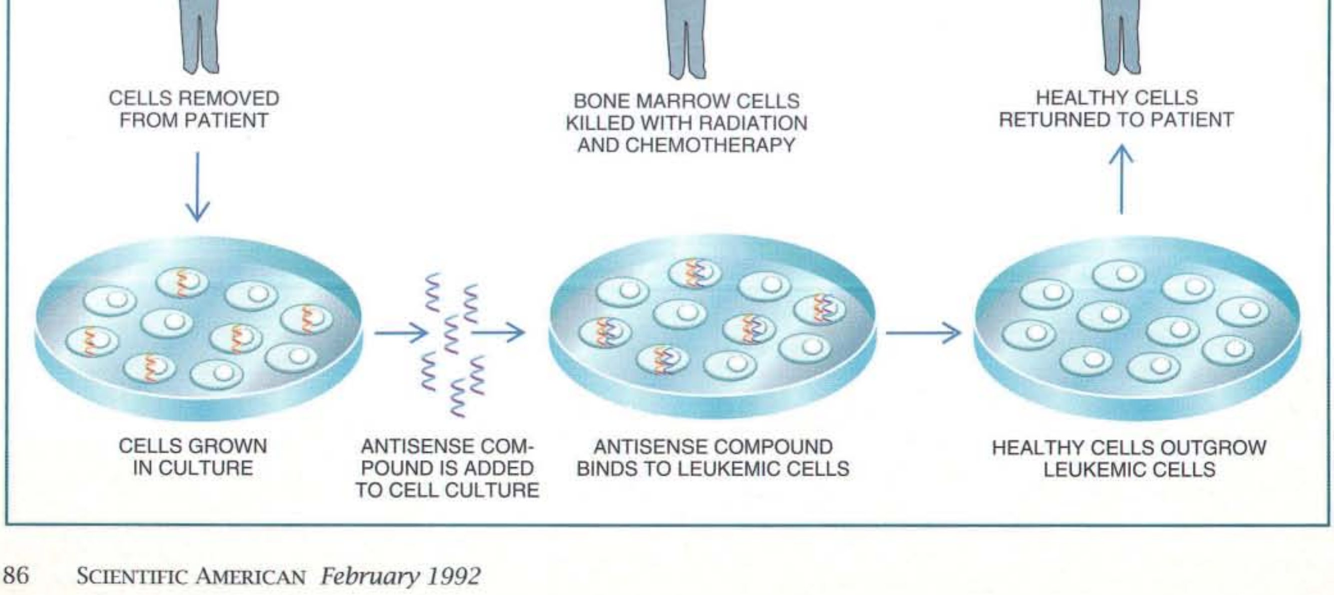
Arthur M. Krieg of the University of Iowa, who is senior editor of the journal *Antisense Research and Development,* comes down on Crooke's side of the argument. Krieg, who has systematically compared antisense compounds, says both types inexplicably fail some tests of activity. But he believes most researchers find Ts'o's methylphosphonates "greatly inferior," in part because they must be present in concentrations up to 100 times greater than phosphorothioates to achieve equivalent effects.

Considerable hurdles remain before either type of antisense compound can become powerful medicines. Krieg wonders how simple it will be to find stable compounds that are soluble enough to pass easily into cells and will not trigger immune reactions. Immune responses to nucleic acid, he points out, can cause systemic lupus erythematosus, a fatal disease. Krieg also worries about the price of the compounds. Topical uses of antisense compounds may precede systemic uses, he believes. Many of Genta's planned products are for topical uses. "There's no reason to choose a favorite technology right now," says James W. Hawkins, president of Synthecell Corporation in Rockville, Md. "It may be that, for example, methylphosphonates will work best in topical applications, and phosphorothioates will be best for systemic uses."

In fact, many companies, including Isis, are now working on entirely new classes of antisense compounds made by modifying not only the backbone but also the base and the sugar components of DNA. Amgen in Thousand Oaks, Calif., has recently established an antisense division and has applied for patents on several DNA analogues. Others, such as Triplex Pharmaceutical in The Woodlands, Tex., are working on antisense molecules that bind to double-strand DNA, which presents a more difficult challenge, but the molecules may be able to bind more specifically.

The arguments over chemistries do not appear to be slowing the field down. "The first generation of antisense compounds is now reaching the clinic, but new compounds are much more attractive," says Crooke, optimistic as ever. "Progress has exceeded everyone's expectation." —*Tim Beardsley*

Treating Leukemia with an Antisense Drug


CELLS REMOVED FROM PATIENT
BONE MARROW CELLS KILLED WITH RADIATION AND CHEMOTHERAPY
HEALTHY CELLS RETURNED TO PATIENT
CELLS GROWN IN CULTURE
ANTISENSE COMPOUND IS ADDED TO CELL CULTURE
ANTISENSE COMPOUND BINDS TO LEUKEMIC CELLS
HEALTHY CELLS OUTGROW LEUKEMIC CELLS

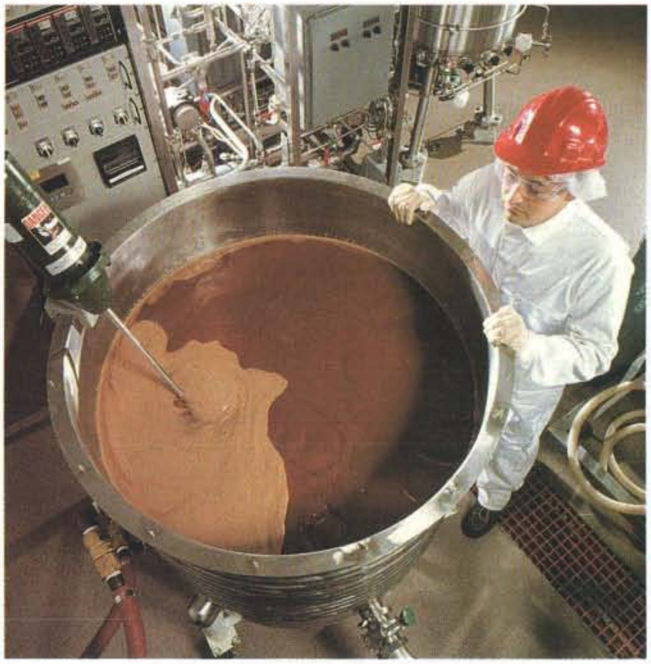
A Better Red

Another candidate in the search for a blood substitute

Scientists had just begun feeling confident that they could screen the national blood supply for hepatitis, when the AIDS virus appeared. No sooner were detection procedures for it devised and routinized than 100 soldiers returned from the Persian Gulf War with "Baghdad boils," a parasitic infection that physicians are concerned could be transmitted through blood.

The risk of infectious disease is just one of the reasons scientists are seeking a blood substitute. Transfusions require complex blood typing and cross matching. Accident victims, soldiers and people with rare blood types can die while waiting for compatible fluid. Additionally, whole blood must be kept refrigerated and even then has a shelf life of only 42 days.

The search for a safe way to duplicate the oxygen-carrying capacity of blood has been a long and frustrating one. Two companies that have tested animal hemoglobin in humans have been compelled to cancel the trials because of side effects. But another would-be champion has entered the list. Somatogen in Boulder, Colo., is tackling the problem with a genetically engineered, slightly modified form of the human molecule. It is being hailed as the most promising substitute yet.



RECOMBINANT HEMOGLOBIN is produced in the bacteria* Escherichia coli *at Somatogen in Boulder, Colo.

Somatogen devised its form of hemoglobin in collaboration with Kiyoshi Nagai of the British Medical Research Council in Cambridge. Nagai works in the structural biology laboratory headed by Max F. Perutz, who won the Nobel Prize in 1962 for determining the structure of hemoglobin. Perutz's group was the first in the world to perform X-ray crystallography on the protein. The process yields three-dimensional images that reveal the exact positions of atoms. Altering these sites can change the form of a protein and therefore its function.

The molecular images gave the researchers clues to problems that have thwarted other laboratories trying to produce hemoglobin as a stand-in for red blood cells. One trouble is that when hemoglobin is removed from a cell, it binds more tightly to oxygen, releasing only 3 to 5 percent oxygen instead of 20 percent. Adding injury to insult, "naked" hemoglobin also breaks into pieces that are rapidly cleared from the circulation and clog the kidney's glomeruli.

Other laboratories tried to overcome the problems by chemically cross-linking or polymerizing the molecule. Somatogen looked instead for a genetic change that might accomplish the same goals. "We did exhaustive experiments with rational design," recalls Gary L. Stetler, the company's vice president for research and development. Intuition helped as well.

The researchers began looking for a mutant form of hemoglobin that could release more oxygen than normal. They made changes in the gene that codes for the protein, then tested the effects of the alterations on the protein's structure. Out of some 20 forms, one had all the characteristics they were seeking. Two single-amino acid changes to the hemoglobin gene made all the difference, Stetler explains.

The first change was based on the information gained by X-ray crystallography. Nagai, Stetler and their co-workers saw that inserting a single amino acid resulted in a hinge between two chains of the molecule that otherwise break apart. The second alteration was more intuitive, based on what the teams observed in naturally occurring human variations. The new forms' reduced affinity allows the hemoglobin to release one third of the oxygen it carries.

The modified hemoglobin is produced as a completely folded protein inside *Escherichia coli,* a bacterium that is used as a molecular factory to make many gene-spliced products. Within 24 hours, vats containing the bacteria are blood red, and protein is ready for harvesting. The *E. coli* cells are burst, and the product is run through a column that strips off protein, including an endotoxin the bacteria add on.

The presence of the endotoxin, however, has opened the company to criticism from competitors, especially DNX in Princeton, N.J., which intends to manufacture another version of recombinant human hemoglobin in transgenic pigs. Charles H. Scoggin, Somatogen's president and CEO, defends the simple purification step, saying it yields a product with toxin levels far below those already accepted by the Food and Drug Administration for human serum albumin. "You can't steam-sterilize a pig," he retorts.

The failures of other companies developing hemoglobin continue to cast shadows that only the human trials can dispel. Somatogen planned to begin tests in January and have its first clinical data available by midyear. Researchers suspect that the previous side effects arose from impurities engendered by the move from test tube to large-scale manufacturing. But the question remains open as to whether there is something inherently toxic about hemoglobin circulating without red blood cells.

If recombinant hemoglobin finally does perform as expected, the market might well expand beyond the 7.7 million units of red blood cells currently transfused in the U.S. every year. "We are very cautious about using blood cells today," notes Harvey G. Klein, chief of transfusion medicine at the National Institutes of Health's clinical center. "We're always looking for the minimum red blood cell count, or hematocrit, that will allow a patient to get through surgery or trauma without harm."

But given a substitute, Klein thinks all that would change. "You don't look for the minimum amount of penicillin that will get you through pneumonia. If we had a safe and effective alternative to red blood cells, I think we'd use it a lot more. I would, I wouldn't take a chance." *—Deborah Erickson*

Further References

An electronic journal adds a new dimension to reporting research

Louis Pasteur was among the first scientists to supplement with precise documentation the practice of communicating with colleagues by word of mouth or through informal letters published in journals. In his papers, Pasteur formally segregated the methods he used from his analysis and conclusions, enabling other scientists to readily repeat his experiments.

The enormous storage capacity of the compact disc promises to take a contemporary researcher one step further. Interested readers will be able to repeat a part of the experiment—and test some hypotheses of their own.

A template for this new type of scientific journal is a publication of the U.S. Geological Survey (USGS) and several other federal agencies whose operation depends on the processing of gigantic hoards of remote-sensing data. Called Arctic Data InterActive (ADI), it is one of the first technical publications to use compact-disc read-only memories (CD-ROMs), which store more than 250,000 pages of text on a single 12-centimeter-diameter platter, as something more than a huge electronic bookshelf.

An article on Alaska's Malaspina Glacier by Bruce F. Molnia, USGS chief of international polar programs, and John E. Jones, former radar specialist for the USGS, provides evidence that the glacier's undulating surface mirrors the underlying topography. The conclusion was based on an analysis of side-looking airborne radar (SLAR) images of the glacier and was later confirmed through field investigations.

A reader can choose to display on screen the same radar image that originally appeared in a 1989 edition of the journal *EOS Transactions,* a publication of the American Geophysical Union. This image is created from the actual digital values for radar reflectance that were gathered by SLAR on a Lear jet flown by a USGS contractor.

After studying the radar picture, the user has access to some of the same image-processing software that remote-sensing specialists use to examine an image. Parts of the image can be sectioned off; color, shading, contrast—even roughness—can be controlled to highlight the contours of the glacier. "The reader can do virtually everything we did," Molnia says. (Not quite: the disc does not include a round-trip ticket to Alaska.)

ADI incorporates features that are now becoming recognized under the term "multimedia." To move between article text and data, ADI uses a software approach called hypermedia, which links related reference points in the data to the familiar context of the scientific journal article. "We tried to take the best elements of print media and combine them with the power and elegance of multimedia," says Denise A. Wiltshire, project chief at the USGS, who worked with InterNetwork in Del Mar, Calif., to design the software.

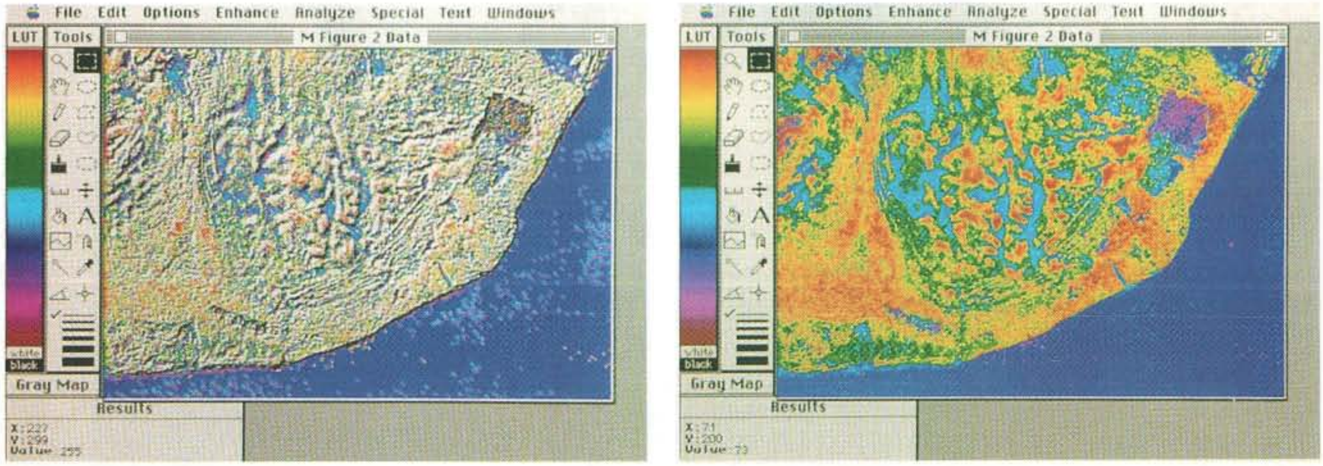
The electronic publication also includes a sociological profile of Alaskan Inuit hunters, illustrated with photographs of hunters reproduced from the Smithsonian Institution, and tables on the sex ratios and age characteristics of the bowhead whale, which is hunted by the Inuit. Future versions might add sound in the form of an oral history of Inuits, an idea that was left out of the original version. Instead of the reader having access to mere references to related publications, the entire text of those articles might be included.

Before a multimedia scientific journal is delivered to subscribers every month, several financial and logistical problems must be resolved. ADI cost the agencies $100,000—the same amount it would have taken to produce dozens of different CD-ROM titles of existing compendia of bibliographic citations. Wiltshire counters, however, that journal production costs will be substantially reduced because a working framework, or "shell," for a multimedia journal has been developed.

Putting together such interactive journals will differ significantly from the publishing of their paperbound predecessors. Specialists with skills akin to those of a video producer will be required to integrate the various media. Until standards are developed for submitting research data, a journal's production staff may have to spend considerable time correcting inaccuracies or reconciling differences in data-collection methods.

Whether there is a routine need for this much information is also sure to be a matter for debate. Robert A. Day, a professor of English at the University of Delaware who teaches scientific and technical writing, says the best papers are often ones in which the author and peer-review panel have coaxed out a clear synthesis of the scientist's ideas and methods, often making it unnecessary to append the researcher's original data. "We don't want every paper to look like a Ph.D. thesis," Day comments.

Perhaps the most provocative argument favoring the publication of a multimedia science journal is that readers could test and challenge the conclusions of the researcher. "If something is precise to the fourth decimal place," Molnia says, "people would immediately question it." —*Gary Stix*



ALASKAN GLACIER can be viewed in a prototype for a new multimedia science journal by using image-processing software to highlight the topography* (left) *or color* (right) *of the landscape. Photos: InterNetwork.

THE ANALYTICAL ECONOMIST

The Discreet Disappearance of the Bourgeoisie

Remember when it seemed everyone shopped at Sears and pasted stamps into books that could be traded in for toasters and cake dishes? Most Americans confidently felt they were part of the middle class—and three quarters of them were. Moreover, for more than three decades after World War II, the distribution of income in the U.S. stayed roughly the same.

The stability of the middle class puzzled economists, recalls Greg J. Duncan of the University of Michigan. Expansions and recessions barely dented it. The Great Society and a raft of other social programs couldn't dislodge it. Some people moved up from poverty, others fell down; some became wealthy, others dropped back to the middle class. Tax cuts and tax hikes alike made little difference to the proportions of rich, middle and poor.

Until the 1980s, that is. The past decade has brought such sharp changes in the distribution of income in the U.S. that Duncan says economists are even more at a loss to explain income disparities than they were in the face of the earlier stability. The middle class, which for decades comprised roughly 75 percent of the adult population, shrank by about 10 percent.

Along with Timothy M. Smeeding of Syracuse University and Willard Rodgers of Michigan, Duncan tracked economic transitions among a group of 7,300 households whose members have been studied since 1968. Until 1980, migrations to and from the middle class more or less offset each other, leaving the relative size of each income bloc largely intact. For instance, during those years, a "middle-class" adult—one who earned between $18,500 and $55,000 in 1987 dollars—faced about a 6 percent chance of entering the upper class within three years and a similar likelihood of slipping into the lower class. At the same time, 31 percent of upper-class adults would fall from economic grace even as 35 percent of lower-class adults would climb up into relative comfort.

Since 1980, however, rates of departure from the middle class have increased significantly: 2 percent more people have risen to the upper income bracket, and 30 percent more have slid into the lower economic tier.

At the same time, fewer people from either the upper or lower income groups are moving into the middle group, further accelerating the shrinkage. Duncan and his colleagues estimate that between 1980 and 1986, about 30 percent of those in the lower class at any given time could expect to reach the middle class within three years; 27 percent of those in the upper income realm might expect their circumstances to diminish significantly.

The most proximate cause of middle-class erosion is the changing structure of the job market. High-status workers—mostly those who have completed college—are earning more, while lower-ranking workers are earning relatively less. Disparities between top earners and bottom earners have been increasing since the 1960s, but after the late 1970s the gulf between the working poor and the working rich widened even faster. Peter Gottschalk of Boston College calls the result a "tidal wave of inequality" in earned income.

More Americans are rich now—and more are poor. Fewer have stayed in the middle class.

Although the earnings gap of the 1980s is a global phenomenon, other countries' income distributions were altered less than those in the U.S. The difference, Duncan asserts, is that the U.S. social safety net is set much closer to ground level. In Europe, wage earners were hit as hard by the early 1980s recession, "but family incomes were protected" by government benefits. Later on, the economic expansion of the mid-1980s failed to improve the lot of poor Americans. Significant increases in work hours among the poor were offset by an inflationary decline in real wages, reports Rebecca M. Blank of Northwestern University.

Comparisons between Europe and the U.S. indicate poor families in both places experience about the same amount of variation in their income from year to year, but the base level around which incomes vary is higher in Europe. As a result, Duncan says, fewer than 3 percent of European households earned less than 50 percent of the median income for several years in a row, compared with 14 percent of U.S. households.

Some economists have suggested that the U.S. distribution of income is somehow naturally more unequal than that of other countries. After all, the U.S. is geographically and racially more diverse than Europe. Nevertheless, Smeeding notes that even the highest-income regions of the U.S. have significantly higher rates of poverty than all but the poorest nations of Europe. Romania or Bulgaria might have similar percentages of poverty, he says, but theirs is hardly a standard for the world's richest nation to aspire to.

Even if blacks, the racial group with the highest poverty level, are eliminated from the calculations, the U.S. still has twice the European rate of poverty, Smeeding adds. And American poor work just as much as the poor of European nations, if not more. More single mothers in the U.S., for example, have jobs than in Great Britain (although fewer than in Sweden, where liberal child-care allowances make it easier to combine family and employment).

If the exodus from the bottom of the middle class can be traced to a lack of government support for the working poor, that still leaves departures at the top to be explained. According to data Duncan, Smeeding and Rodgers have collected, the story there is pretty much the same as it always was: "Local boy makes good." Although income from two careers is pushing an increasing number of households over the threshold to the upper class, higher salaries earned by men account for the bulk of upward mobility. In addition, many are moving up simply because the salary of the top 10 percent of wage earners is now at least 3.8 times that of the bottom 20 percent, as compared with 2.6 only 25 years ago.

Will the middle class eventually become a minority in the U.S.? Current numbers suggest there is no danger of that before the turn of the century at least. Nevertheless, the trend seems ominous. As long as the work force is increasingly segregated into professionalized, high-paying jobs and less skilled, low-paying ones, Duncan predicts, the middle will be threatened.

—Paul Wallich and Elizabeth Corcoran

MATHEMATICAL RECREATIONS

by Ian Stewart

The Kissing Number

Marvin Q. Mogul glanced out the window at the red sands of Mars. As president of Mars Television, he had the largest, most expensive window in all of Syrtis City. It was superinsulated to protect against the frigid nights. Mogul was so frustrated he was tempted to throw his chair through the glass. His rival at Cosmic News Network had just broken a story about the discovery of ancient Martian artifacts. But that disaster was only the tip of the carbon dioxide iceberg.

It had all seemed so easy when, against heavy competition, Mogul had secured the franchise to broadcast television signals to the new Martian colonies. If only it hadn't been for that confounded efficiency clause! His lawyers had assured him that it was harmless: Mars Television would be required to build a broadcast system that was more efficient than those proposed by his competitors. But now the Supreme Court had ruled that if anyone developed a superior scheme at any later date, Mars Television would lose the franchise. If that happened, the company would run into serious cash flow problems, and then—well, it would be simply too dreadful to contemplate.

He reached for the intercom. "Cressida, get Fogsberry and Cosgrove in here at once." He then turned his attention to a large Martian globe that sat on his desk. Its surface was covered with sticky plastic disks, and every so often he rearranged them. In a gesture of futility, he now threw a disk across the room and accidentally hit Fergus Fogsberry, who had just entered through the door.

"I guess you're upset about the CosNN report on the artifacts?" Fogsberry gasped.

Mogul grunted in irritation. Fogsberry took the hint and kept quiet. Then he became aware of the globe, raised his eyebrows and sat down. "A new layout, Marvin? I thought that was all settled months ago. Eight transmitters, one at each corner of an imaginary cube."

"It *was* all settled months ago, Fergus, but now our plans are worthless, thanks to the Supreme Court. We can't just offer better coverage than Phobos Booster Satellites did when they bid against us; we've got to offer the best possible coverage."

"Let's do it. It may cost more, but—"

"I don't mind spending the extra money, Fergus. I just don't know what the best coverage is!"

At that moment, Basil Cosgrove burst into the room, panting heavily. He had taken an ill-advised shortcut through the thin atmosphere without wearing his Self-Contained Extraterrestrial Breathing Apparatus. "Hey! Did you see that CosNN report on the artifacts—" Fogsberry waved at him to be quiet. Ignoring Cosgrove's exclamation, Mogul patiently began to reiterate the transmitter problem, but Cosgrove soon interrupted him.

"Sorry, Chief, but we need to sort out the details first. Like, what does the Supreme Court mean by 'best coverage'?"

"According to our lawyers, the justices effectively mean we have to provide television services to the largest possible area of Mars."

"Let's saturate the place, then," Fogsberry said. "Put up so many transmitters that the coverage is 100 percent."

Mogul struck the side of his head with the heel of his hand. "Brilliant! Now why didn't I think of that? Cressida, get me Construction—"

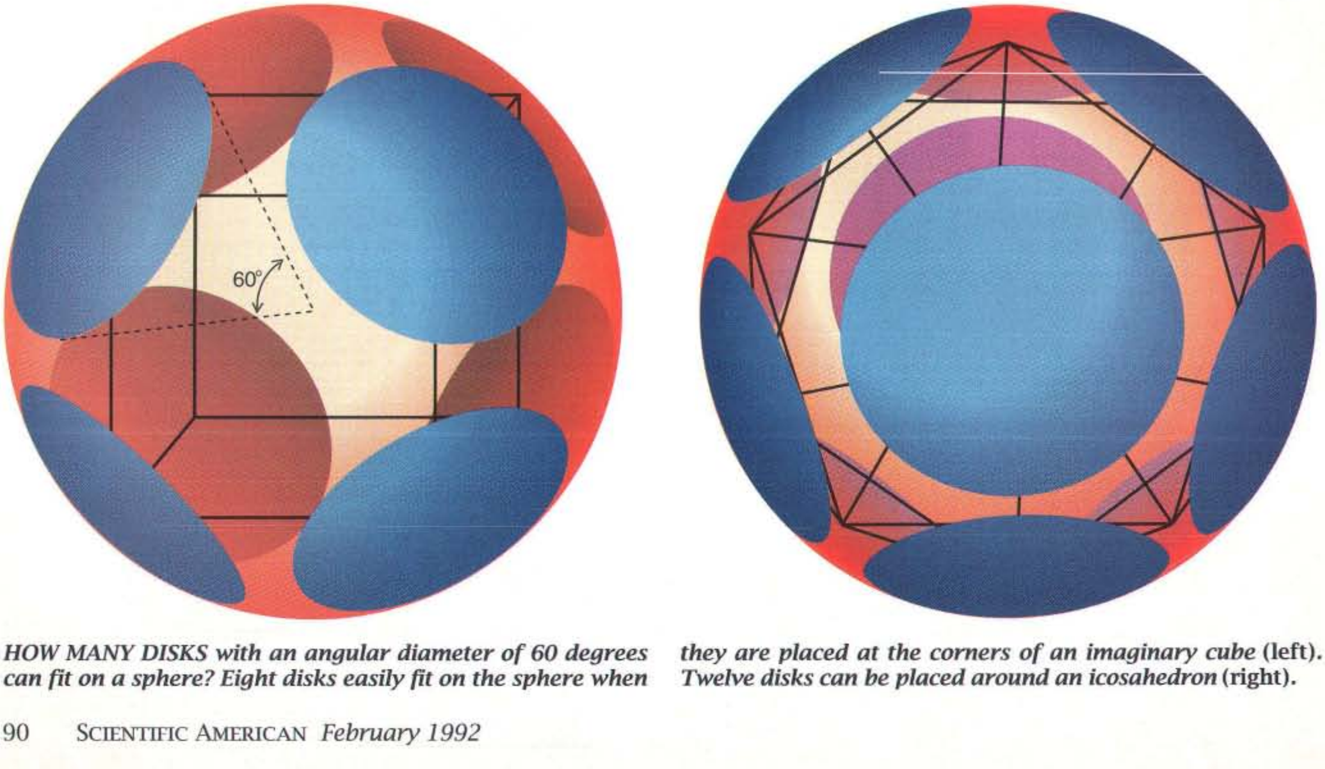
"Sorry, Chief," Cosgrove murmured. "That won't work."

"Why not?"

"If two transmitters have overlapping zones, it causes interference. The picture goes fuzzy, or sometimes you see funny shadows and multiple images."

"That's a serious problem?"

"I'm afraid so," Cosgrove said. "Un-



HOW MANY DISKS with an angular diameter of 60 degrees can fit on a sphere? Eight disks easily fit on the sphere when they are placed at the corners of an imaginary cube **(left).** ***Twelve disks can be placed around an icosahedron*** **(right).**

less we want to lose the franchise. If we transmit bad pictures, the opposition will use our intestines for bootlaces."

"Cancel that, Cressida," Mogul barked over the intercom.

"Could we squeeze any extra transmission zones in between the existing ones?" Fogsberry asked.

"Depends how much room there is," Cosgrove replied. "Each zone has an angular diameter of 60 degrees, and—"

"Hang on," Mogul declared. "What's an angular diameter?"

"Mars," Cosgrove said, "is a sphere. The transmitters reach a zone that we tend to call 'circular,' but actually it's a spherical cap with a circular boundary, a circle that's bent to fit on a sphere. The angular diameter is the angle between two points on opposite sides of the circular boundary as measured from the center of the sphere."

"And that's 60 degrees," Mogul added.

"Right," Cosgrove continued. "Now, the original proposal specified eight transmitters placed at the vertices of an imaginary cube. I calculate that the angular separation between neighboring transmitters is—" his voice tailed off as he punched keys on a portable computer. "Hmm. A bit more than 70 degrees. Good. So they don't overlap; in fact, there's a 10-degree gap between them. Um. What was the question?"

"Can we fit any extra transmitters in between?" Fogsberry repeated.

"Let's see. The biggest gaps are where the centers of the faces of the cube would be. The angular separation from one vertex of the cube to the opposite one on a face is—hmm, about 109 degrees. Each transmitter covers an angular diameter of 60 degrees, that is, an angular radius of 30 degrees, so the gap between them is about 109 minus 30 minus 30 equals 49." Cosgrove looked expectantly at Fogsberry.

"Into which we want to fit a 60-degree transmission zone."

"Yes, Foggy, my astute friend."

"So there isn't enough room."

"Precisely." They all sat in silence for a few moments.

"Maybe we could shrink the zone, though," Cosgrove remarked. "Chief, ask Cressida to get Engineering on the horn and find out how much variability there is in zone settings."

A minute later Cressida stepped into the office. "Boss, I've found out what variability there is in the transmitters."

"Great! How much?"

"None."

"None? What do you mean, none?"

"It's the new system the manufacturers use," she said apologetically. "It's on the labels on the boxes. They just say, 'TV transmitter—no user-serviceable parts inside.' We can't change the settings. It's 60 degrees or nothing."

"That's the increasing sophistication of modern electronics for you, Chief," Cosgrove snorted.

"Wait a minute," Mogul said. "If we can't fit any more in, then we must have found the best arrangement."

"Sorry, Marvin, but it's not that simple. Just because you can't add transmitters to the existing arrangement doesn't mean that some totally different arrangement might not work better."

Mogul returned to peeling sticky disks off the globe and sticking them back on again.

"If you put that one over there—" Fogsberry interrupted.

"I think we should rip them all off," Mogul commented.

"We do, boss. All the time."

"No, not the customers. I mean rip off the disks and start again. Try to cram them together as much as possible. Leave plenty of room for the rest."

"Oh, right. Hey, that looks good! How many have you got, Chief?" Mogul counted 11 disks.

"It's a good thing we did this," Mogul said. "Imagine what would have happened if we'd stuck with the cube arrangement in our bid and then some smart aleck at Cosmic News Network went to the Supreme Court with this arrangement instead."

"If CosNN lives up to its reputation, Chief, it'll grab the goodies."

"Precisely."

"So if we go for your new arrangement of 11 transmitters and CosNN finds a way to squeeze 12 in somehow, we're dead."

"The maximum must be 11," Mogul said. "I don't see a way to improve—"

"I've got just 12 disks on the globe," Fogsberry yelled. "I put them at the vertices of an icosahedron," he explained. "But there's still a lot of room. If they weren't sticky, you could slide them about all over the place. Maybe there's room for 13?"

"I've got an idea," Cosgrove chirped. "If we compute the total surface area of the sphere and divide it by the area of one transmitter zone, that puts an upper limit on how many can be crammed in. Yes, I know we're not taking the gaps between disks into account, but at least we'll have something to go on."

"Excellent, Cosgrove. Proceed," Mogul commanded.

"Right. Let's assume the radius of Mars is one."

"I hate to split hairs, Cosgrove, but it's 3,390 kilometers."

"One unit, I mean. It doesn't matter which units we use, but the calculations are easier if the radius is one. Then the surface area is 4π. The area of a 60-degree spherical cap is—hmm—$(2-\sqrt{3})\pi$, or about 0.2679π. So the number of zones must be less than or equal to $4\pi/0.2679\pi$, or 14.9. Since the number of zones must also be a whole number, the maximum is 14."

Kissing Numbers

DIMENSION	LOWER LIMIT	UPPER LIMIT
1	2	2
2	6	6
3	12	12
4	24	25
5	40	46
6	72	82
7	126	140
8	240	240
9	306	380
10	500	595
11	582	915
12	840	1,416
13	1,130	2,233
14	1,582	3,492
15	2,564	5,431
16	4,320	8,313
17	5,346	12,215
18	7,398	17,877
19	10,668	25,901
20	17,400	37,974
21	27,720	56,852
22	49,896	86,537
23	93,150	128,096
24	196,560	196,560

"Thank you, Cosgrove, but that doesn't help us decide whether 12 is the best. It could be 13 or 14 instead," Mogul said.

"It seemed worth a try, Chief. If only there was some way to relate our problem to a mathematical puzzle that has been solved before. Wait a minute."

"Cosgrove, if all you can do is—"

"The kissing number!" Cosgrove exclaimed.

"Cosgrove, Mars TV does not broadcast that sort of program," Mogul frowned. "Though maybe—"

"Excuse me, Chief. I was referring to the kissing problem. You may have heard of it. How many equal spheres can touch a single sphere of the same size without intersecting one another?"

"I don't quite—"

"Think about it in two dimensions, first," he said. Cosgrove dug in his pockets and pulled out a handful of pennies. He put one penny down on the table. "What's the largest number of pennies that can be placed around this one so that they all touch it?"

Mogul fiddled with the coins for a few seconds. "Six," he said. "They just fit around it."

"Our problem is just like that, but with spheres instead of circles," Cosgrove said. "We need to know what's the greatest number of ball bearings that can be arranged around a single bearing if they are all the same size."

"Cosgrove, our transmitter zones are circles, not ball bearings," Mogul said.

"Spherical caps, actually, Chief. But that's not the point. Imagine two equal spheres touching. If you project one sphere radially onto the other, you get a spherical cap of angular diameter 60 degrees. Any nonoverlapping arrangement of 60-degree caps—our zones—corresponds to an arrangement of 'kissing' spheres. So our problem is the kissing number problem for three-dimensional spheres, thinly disguised."

"I thought that spheres were always three-dimensional."

"Well, you can ask the same question in space of any number of dimensions. Let me dig out my old notes." He muttered rapidly into a battered personal disorganizer. "Yes, look, here's a table of the best-known results for dimensions up to 24."

They inspected Cosgrove's notebook [*see table on preceding page*]. "The exact number is known for one, two, three, eight and 24 dimensions," Cosgrove stated. "Until recently, I would have added 'and no others,' but there's some news rippling through the airwaves. Wu-Yi Hsiang of the University of California at Berkeley has announced that he has solved the problem in four dimensions: the answer is 24."

"You mean to say the answer is unknown in five dimensions but known in eight? And 24, for heaven's sake?" Mogul asked. "Why?"

"Well, in five dimensions an arrangement with 40 spheres is known, and it's also known you can't get more than 46. But nobody has yet closed the gap."

"Fine. But why are eight and 24 dimensions easier than five?"

"Andrew M. Odlyzko and Neil J. A. Sloane of AT&T Bell Laboratories found a way to estimate a good upper bound for the problem in eight and 24 dimensions," Cosgrove remarked. "It was so good that it turned out to be the same as the best-known arrangement of spheres. So that was that."

"It still doesn't explain why," Fogsberry objected. "It just says it's true."

"Well," Cosgrove said uncomfortably, "there's something rather unusual about eight- and 24-dimensional space. All kinds of sphere-packing problems work out nicest in those dimensions."

(Readers of this department may find it hard to get hold of 24-dimensional spheres, but there are many similar problems they can tackle—for example, finding the smallest circle or square that will contain a given number of pennies or figuring out the kissing numbers for planar shapes such as pentagons or ellipses. If you feel really ambitious, you might like to tackle the problem of the Martian transmitters with zones whose angular diameter is some value greater or less than 60 degrees. And if you are looking for a truly mind-boggling puzzle, you might think about what the greatest angular diameter of a zone would be if you wanted to fit a given number of identical zones on a sphere without overlap. Mathematicians have found answers for up to 12 zones, and they have conjectured solutions for a few larger numbers.)

Mogul interrupted the discussion. "According to your table, the kissing number in three dimensions is known to be 12."

"Yes," Cosgrove answered. "Isaac Newton and David Gregory argued about it in 1694. Newton claimed the answer was 12. Gregory thought 13 might be possible. In the 19th century C. Bender, R. Hoppe and S. Günther offered proofs that Newton was right—"

Cosgrove paused for breath, then rushed ahead before anyone could stop him, "—but the proof is far from easy. One source of difficulty is that the arrangement isn't rigid: there's a lot of freedom to slide spheres around. In fact, you can rearrange the 12 spheres in any way you like by sliding them without intersecting, always touching the central sphere. So they don't have to be at the vertices of an icosahedron. That's one reason why the eight- and 24-dimensional versions are solved. There is really only one way to arrange the spheres in those dimensions. It's always easier to pin down an answer when there's only one of it, so to speak."

"How did Hsiang solve the four-dimensional case?" Fogsberry asked.

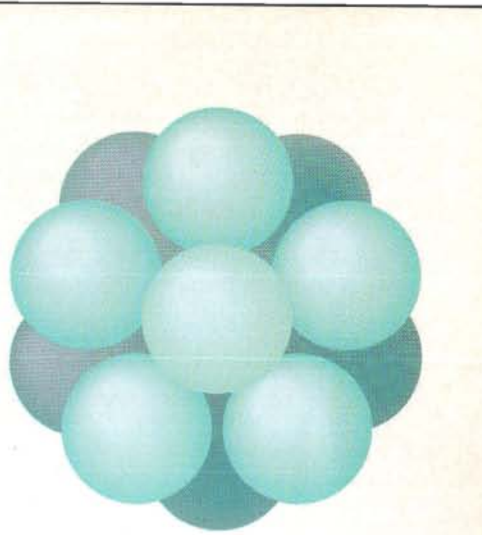
"He recently solved a very important problem related to sphere packing—the best way to pack spheres in three dimensions, a problem that goes back to Johannes Kepler in 1611. Hsiang has announced that his new techniques also work on the four-dimensional kissing problem. But," Cosgrove went on, "I haven't seen the proof yet."

"Who cares?" Mogul growled. "We know that in three dimensions, 12 is the maximum, and we're safe if we use an icosahedral arrangement. Cressida, get me Construc—"

"Chief, you know I've been trying to tell you about what Cosmic News Network reported this morn—"

"I've told you, I'm not inter—"

"You should be. Seems that some very strange machinery was found among the Martian artifacts, and some of it is still working! The archaeologists have already started to experiment with the equipment, and—"



THIRTEEN SPHERES of the same size (11 of which are visible) can be arranged so that one sphere in the center touches the other 12.

The ground seemed to shake without actually moving. Everything suddenly looked different, but exactly the same. It was very disconcerting. "Oh-oh," Cosgrove said. "They were right."

"Right about what?" Mogul snapped. "Well? Out with it, man!"

"A dimension-quake. Mars has just become 24-dimensional."

Mogul looked out of his window at a 24-dimensional mountain and suddenly became very excited. "Cosgrove, will the dimension-quakes have any effect on currency?"

"None, Chief, except that two-sided coins will now have many more faces."

"Fantastic! Cressida, call CosNN and offer them the franchise for free."

"Boss, I think all these quakes have rattled your brain."

"Not at all. Whoever builds the network will now have to buy 196,560 transmitters at about $1 million each. That's a cool 200 trillion. I want to see CosNN pay *that* out of their heretofore three-dimensional bank account."

"Ah, Chief," Cosgrove said softly. "Did I mention the artifact that turns stone into gold?"

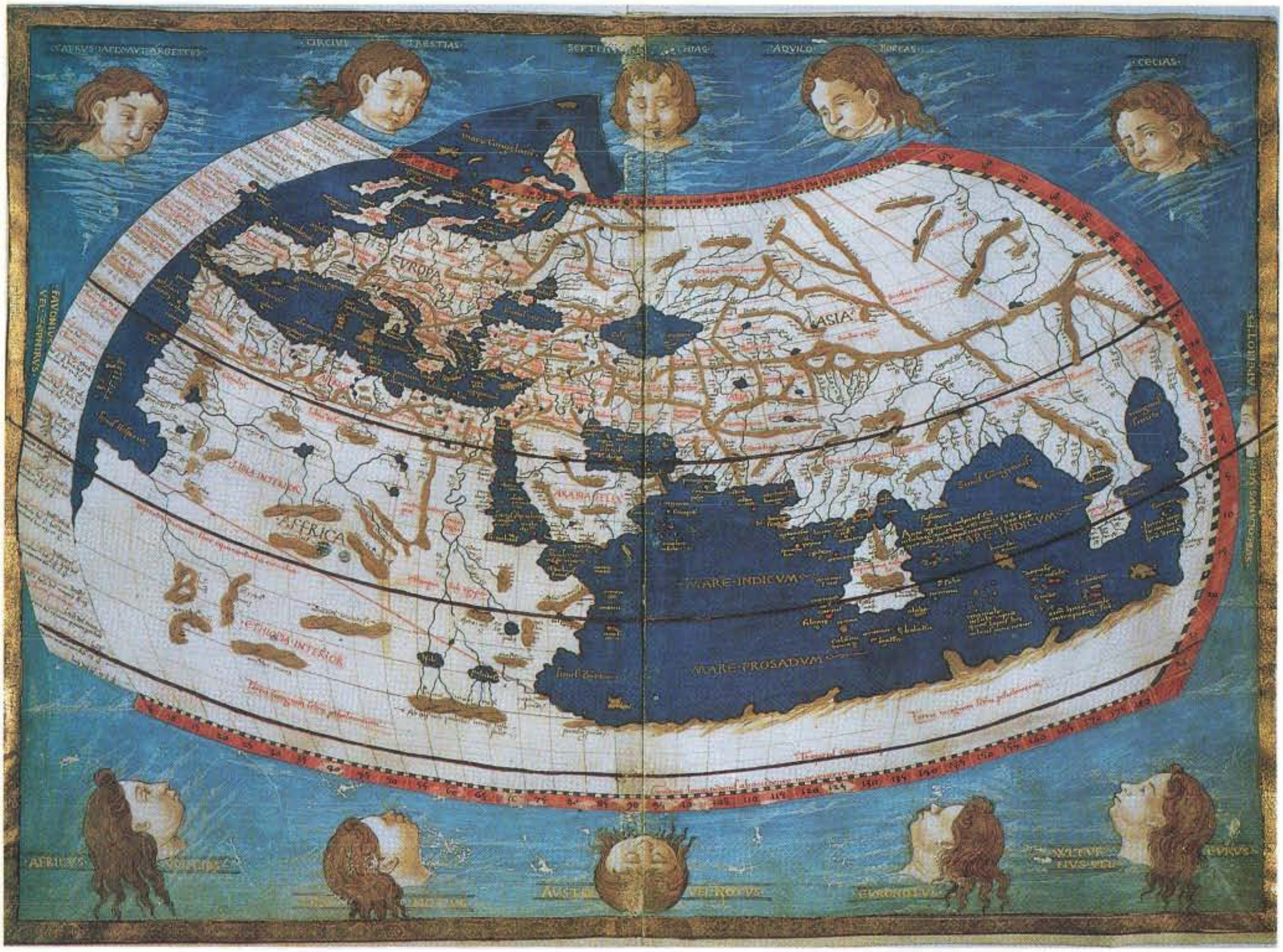
FURTHER READING

THE PROBLEM OF THE THIRTEEN SPHERES. John Leech in *Mathematical Gazette,* Vol. 40, No. 331, pages 22–23; February 1956.

SPHERE PACKINGS, LATTICES AND GROUPS. John Horton Conway and Neil J. A. Sloane. Springer-Verlag, 1988.

SPHERE PACKINGS AND SPHERICAL GEOMETRY—KEPLER'S CONJECTURE AND BEYOND, preprint. Wu-Yi Hsiang. Center for Pure and Applied Mathematics, University of California, Berkeley, July 1991.

BOOK REVIEWS by Philip Morrison



WORLD MAP compiled in the second century A.D. by Claudius Ptolemy, reproduced in Florence in 1474.

Geography circa 1492

ATLAS OF COLUMBUS AND THE GREAT DISCOVERIES, by Kenneth Nebenzahl. Rand McNally & Company, 1990 ($75).

The new-book tide is brimming with volumes that mark the half-millennium since the voyage that forever stitched the Old World to the New. Only the most pleasing of such books will be noted here during 1992; many others are first-rate as well.

This large, handsome atlas, neither lavish nor dauntingly heavy, is a logical first choice. You will find more than 50 period maps or charts, each photographed in its entirety in color and most presented over a full double spread; most of the originals are so large that another single page gives a welcome close look at some telling detail. A learned but nontechnical page of text establishes the place of each map within the fateful unfolding of conjecture through knowledge to power. The trail begins with Ptolemy and goes all the way to Edward Wright's world, the one map that adorned in a copperplate engraving Richard Hakluyt's prose epic, *The Principal Navigations... of the English Nation.*

One pair of maps helps to show how this purposeful compilation deepens the wide appeal of cartographic history. An illuminated world map is the first to record the deeds of the Portuguese navigators; it can be dated to 1502 from its reference to the feared loss of one exploring ship. Its creator is anonymous; the map is named after an intelligence agent of the Duke of Ferrara, the city where it is now held. That diplomat somehow smuggled the classified document out of Lisbon. Vertically across the green and orange shoulder of Brazil on the map runs a strong meridian line, the Pope's demarcation of 1494, parting forever the claims of Castile from those of Portugal. It was not hard to project such a line west of the Cape Verde Islands: the newfound Antilles and all the Americas westward for Spain, while Lisbon gained all the new lands from Brazil to the scented islands eastward around the world.

But just where on the other side of the world did Portuguese rights end? No one could well say. Only after Magellan's sole surviving ship returned from its globe-girdling voyage did the two realms contest the Moluccas, "richest spicery of the Orient." The cartographers were up to the task. Here is another map, by the expert Juan Vespucci, nephew to famous Amerigo himself.

It is the first polar-projection map of the two world hemispheres, made to show graphically just how the papal meridian would extrapolate across the pole to divide the antipodal tropics.

In 1524 the diplomats and the navigators met (there was a Cabot, a Columbus, Magellan's pilot Elcano and many another) to settle the matter. Each side had its confident and redoubtable experts; none of them really had firm map longitudes in hand. The conference debated at length, but to no conclusion. Five years later Charles V sold his rights to the Portuguese; his captains had twice failed to make a safe westward journey along Magellan's path into the wide Pacific.

The maps of the atlas are convincingly divided into periods by our connoisseur author. An example or two from each of the four periods must suffice to outline the story the mappers tell, as interesting as it is visually enticing. The first period documents the long cartographic tradition of conjecture that Columbus elaborated into a justification for his bold westward voyages. One of eight maps is the colorful terrestrial globe made by Martin Behaim in Nuremberg, dated in 1492 itself, based on the very maps Columbus knew. The wealthy island of Cipangu (Japan) is entered close to the coast of Cathay, no long voyage west across the Ocean Sea. (This illustration is a little disappointing; the globe is beautiful, its labels fascinating, but the view shown does not clearly include the stretch of sea Behaim represented between the Canaries and his Japan nearby.)

Fifteen maps come from Columbus's own time, the 30-something years between his first voyage and the time of swift Spanish conquest on the mainlands. One of these is a set of three sketches in pen and ink, hand drawn by an Italian cartographer and the Admiral's brother, Bartolommeo Columbus, after the fourth voyage. The little maps were eventually published by 1522. It is a family view of the round world near the equator. It shows the Mondo Novo, Venezuela and Honduras arranged eastward along one coast that continues out eastward from Asia, beginning only a little way south of the old Cathay drawn by Ptolemy. A few pages later we see the map that first named America (1506) and showed as well a wide but unreal strait that opened across Panama to the South Sea, long before any real canal.

The third batch of maps begins to fill in the New World as it is. Cortés himself drew an urban plan of the watery Valley of Mexico and a striking small plan of the entire Gulf of Mexico, marking Florida and the mouth of the Mississippi. Cortés credited his Mexican coastal detail to information straight from Montezuma! The maps improve, both in the elegance of their ornament of sea beasts and ships and indigenous houses and in factual detail.

In 1569 Gerardus Mercator published his first world map using the projection named for him. His world map here in copperplate is typical of "Renaissance scientific accomplishments," not free of paradox between new knowledge and old fancies. It was not until Edward Wright's work at the century's end that the ideas behind Mercator's projection were publicly described and popularly explained.

The fourth group of maps shows Europe entering the period of colonial expansion. We see Cuzco mapped, a capital city in masonry before the cathedral was built from Inca stones. Here is the California coast Francis Drake skirted as he pillaged and traded his way around the world. Dutch mapmaker Jodocus Hondius visited the *Golden Hind* while she was moored at Thameside to honor Drake's highly profitable round-trip. The Hondius world map of 1589, with a vignette of Drake's ship in its uncertain harbor somewhere near the Golden Gate, was from the first an icon, the round world surmounted by Elizabeth's royal seal. This compilation ends as the sea maps of the explorers begin to give way to the maps of military campaigns in the Old World, mines and plantations in the New.

Selective Neglect

WOMEN'S HEALTH FROM WOMB TO TOMB, by Penny Kane. St. Martin's Press, 1991 ($35).

Counting seems simple—we all know the integers—but wherever counts really matter, the task can become unexpectedly subtle. Penny Kane, Australian author and editor of a dozen studies on demographic issues, sets before the fascinated nonspecialist reader an exemplary model of counting to clear purpose. The book is fair-minded, well documented, broadly reflective—and yet brief. The author fills her pages with hard evidence in statistical graphs and tables, mostly taken from WHO assessments and from the British Office of Population, Censuses and Surveys. These numbers alone, even when artfully juxtaposed, speak rather demurely, but once one considers her sharp inquiries into just what has been counted and how, bland tables turn eloquent.

Women around the world now live on average longer than men, and that gap in life expectancy is still increasing, both in poor lands and in most of the affluent ones. Plotted through life year by year, the relative rate of death among males peaks twice; first during their teenage and young adult years and once again, though less sharply, between 45 and 75 years of age.

Only in South Asia are matters otherwise: no bagatelle, for one human being in six resides there. In those impoverished and populous countries, an excess death rate is still seen among women during their reproductive years. Death is unambiguously diagnosed even without doctors, but its causes are still seldom recorded in lands where even the death certificate is unsure. All the same, specific local studies make pretty plain that women's vulnerability in mid-life is linked to pregnancy and childbearing in the absence of adequate medical care. In those circumstances, biology is a kind of destiny, as it was everywhere before Semmelweis and modern obstetrics.

The most dramatic change in life expectancies under modernization has been the change in the curve of death rate plotted against age from a U shape to a J shape, the mark of decisive decrease from the ancient high mortality during the first few years of life. The developing world is plainly in transition toward such lowered rates for infant mortality.

It appears, however, that a strong preference for sons, nowhere wholly absent, remains in Hindu, Muslim and Chinese societies. This "selective neglect of girls" in the earliest years may be as quietly expressed as weaning infant daughters at an earlier age or even trying for the next pregnancy sooner after the birth of a girl. The effects are much the same: less care, affection and food for infant girls, higher risk of bacterial contamination, delayed visits to the health facility. No counts of life and death, however detached, can entirely avoid the somber note of tragedy; here is a toll collected not by nature but by nurture.

To probe death rates more closely, Kane examines the causes. The later chapters treat the more intricate counts drawn for different stages of life from the records of hospital discharges, visits made to doctors, medication and self-medication, even patients' recollections (especially well surveyed in Australia). The main aim is to tease out the reasons for the uniformly greater life expectancy of women in industrial societies. Young men are plainly at much excess risk from accidents and suicide; older men, from widespread coronary disease. The manifest relative longevity of women cannot yet be fully explained: Is it some difference in biological aging or the many behavioral differences in later life that part the sexes?

Big changes are apparent in current life patterns of women in the developed countries. Their span of life is longer by decades; many more marry; their old average of five children now numbers well below three; their chance of outliving their husbands approaches 90 percent. The end of marriage clearly puts men at dramatically greater health risk than it does women. Overall, women suffer a higher level of often undiagnosed minor illness, particularly among the age group between 45 and 64. But they manage to survive their ills very much better than do men.

Specific studies suggest that these mature women are neither hypochondriac nor untowardly subject to mental disorder. Perhaps the trouble is some consequence of the new life cycle, real physical stress during decades of active family rearing, augmented by hormonal change and followed by long years of living alone. Elderly women now end up in institutional care at twice the rate of men in the same age group. "Until somebody notices that women ... are complaining about *something,* the statistics represent little more than a big question mark."

Women ought to be able not merely to survive but to enjoy their longer lives: their osteoporotic bone loss, their joint disorders and their linked endocrine changes are pointers to current medical inadequacy. "A pool of ill-health among women" remains so far unmapped. The implications for research, statistics and training are plain enough.

Why did the mortality curve change so much in industrialized lands? Hygiene, housing, food, clothing, transport, working conditions and hours—all had some role. Especially powerful was the control of microbial infection. But in the developing world it is the education of women that appears more and more the key to the demographic transition from a U to a J. "Wherever girls have more chance of access to education . . . lower rates of infant mortality are found." It is certainly not the physiology she learns in three or four years of village primary school. Survey shows that it is not the wider use of modern infant care, either. Is it a new self-worth, generally leading to a more hygiene-conscious family and a new alertness about the baby? Worldwide the high task remains: pass on the gift of health that women have made to children to the health problems of the women themselves.

Through a Simple Lens

THE LEEUWENHOEK LEGACY, by Brian J. Ford. Biopress Limited and Farrand Press, 1991. (Available from Portland Press Ltd, Commerce Way, Colchester CO2 8HP, U.K.) ($47.50).

In 1668 Robert Hooke's wonderful illustrated *Micrographia* was in its second edition, well on its way to becoming a cult of educated English households. (Sam Pepys had already complained of the priciness of the fashionable purchase.) A prosperous cloth merchant from Delft visited London that year. He must have taken home some memory of the look of Hooke's new small world, perhaps even a copy of the best-seller itself.

That Dutch traveler was the gifted Antony van Leeuwenhoek, as innocent lifelong of the learned academy as he was of Latin or English. But in 1673 he sent to the Royal Society, through a translator, the first letter of some 200 he would prepare during his very long life. These letters recount his acute investigations of the microworld down to a scale several times smaller than Hooke ever saw, the decisive world of microorganisms.

All this he saw and grasped over five decades through the use of 400 or 500 simple, single-lens microscopes, his own design and the proud constructions of his own hands. Leeuwenhoek could not draw, but he supervised many careful illustrations prepared by adept "limners" of just what it was he saw. In 1680 he was named a Fellow of the Royal Society of London, even though Holland and Britain were in or near war throughout those times.

It is about 10 years since the strong room of the Royal Society yielded the last physical legacy of van Leeuwenhoek, annotated microscopic specimens in paper packets attached to his letters, unnoticed by scholars in the three centuries since their 17th-century arrival. It was Brian Ford who found those specimens. He is an expert microscopist, independent and iconoclastic enough to be worthy heir to that prodigious amateur from Delft. Ford gave a first account of the unexpected legacy and what it meant in his eye-opening history of single-lens microscopy, reviewed here seven years ago.

His new book focuses more closely on Leeuwenhoek and his work. Ford begins with a critical survey of our knowledge of Leeuwenhoek's life. He presents full micrographic details of the contents of the packets along with the texts of their covering letters, in facsimile and in translation. We compare the old specimens as seen three ways, through one of Leeuwenhoek's own instruments, through a modern optical microscope and again at the much higher resolution provided by a sophisticated scanning electron microscope (SEM).

The book continues with a careful account, including drawings, of all nine surviving instruments now ascribed to the Delft scientist and of how to use and even to make such tiny bead lenses of high power. Here the author has help from his friends, amateurs and professionals alike in Britain and the Low Countries, who have developed Leeuwenhoek's techniques anew. The book jacket says, quite fairly: "Patient, dextrous readers can, with these pages beside them, make their own Leeuwenhoek microscope."

The old Delft microscopes are small strips of brass or silver sheet, made to be held up to the eye by hand. The sheets sandwich between them one beadlike lens. Simple screw mechanisms allow focus and specimen positioning. The lenses are all double convex or plano convex, made from partly ground or blown glass beads. It is their form, size and polish that count. The working distance of such a lens is a millimeter or less, so that the magnification of the Utrecht example Ford used is about 260. Its resolution is, somewhat surprisingly, better than 1.5 microns. It is essential to limit the light cone that enters the single lens from behind; viewing by a wide cone of illumination destroys contrast, as Leeuwenhoek knew well.

We are shown through the SEM a truly thin section of elder pith, one of the specimens sent in the packets. Leeuwenhoek tells us that he used a shaving razor as microtome to make that thin slice. What we see are a few human red blood cells, "normal contaminants of an open razor." If they are his—a conjecture hard to resist—we may conclude that he shaved with a dry blade, for shaving wet lyses the cells. Another SEM find, only a little less poignant, is an identifiable adult mite found in a specimen of bovine optic nerve he sent to the Royal Society. Leeuwenhoek complained of mites infesting his dried organic materials, and here we see one of them. There is a deeper intimacy in cliomicroscopy than in the most revealing of locked diaries.

Once again Brian Ford has looked into the past through a simple lens to support a vivid, convincing and full-packed analysis. A better index and a single list of published sources would have made this otherwise well-designed book easier to use.

WHY ONLY ONE BIG BANG?

by Geoffrey Burbidge

Big bang cosmology is probably as widely believed as has been any theory of the universe in the history of Western civilization. It rests, however, on many untested, and in some cases untestable, assumptions. Indeed, big bang cosmology has become a bandwagon of thought that reflects faith as much as objective truth.

Yet the momentum this bandwagon enjoys is overwhelming. International conferences on cosmology (which, in the current state of affairs, means only the standard "hot" big bang model) are scheduled at the rate of about one a month. Extensive coverage has appeared in the *New York Times,* the London *Economist* and the *Wall Street Journal,* all based on interviews only with believers in the big bang. Popular monographs such as Steven Weinberg's *The First Three Minutes* have not dealt at all with cosmological theories other than the big bang.

Normally, new ideas in a field of science are advanced by young scientists, who often take a contrary approach. But younger cosmologists are even more intolerant of departures from the big bang faith than their more senior colleagues are. Worst of all, astronomical textbooks no longer treat cosmology as an open subject. Instead the authors take the attitude that the correct theory has been found.

Powerful mechanisms encourage this conformity. Scientific advances depend on the availability of funding, equipment and journals in which to publish. Access to these resources is granted through a peer-review process.

Those of us who have been around long enough know that peer review and the refereeing of papers have become a form of censorship. It is extraordinarily difficult to get financial support or viewing time on a telescope unless one writes a proposal that follows the party line. A few years back Halton C. Arp was denied telescope time at Mount Wilson and Palomar observatories because his observing program had found and continued to find evidence contrary to standard cosmology. Unorthodox papers often are denied publication for years or are blocked by referees. The same attitude applies to academic positions. I would wager that no young researcher would be willing to jeopardize his or her scientific career by writing an essay such as this.

This situation is particularly worrisome because there are good reasons to think the big bang model is seriously flawed. One sign that something is amiss is the time-scale problem. The most favored version of the big bang model yields a universe that is between seven and 13 billion years old. The large range of possible ages derives from uncertainty regarding the rate at which the universe is expanding, a value known as the Hubble constant.

Comparisons between observation and calculations of stellar evolution imply that the oldest known stars are 13 to 15 billion years old, with an uncertainty of plus or minus 20 percent. The estimated age of the elements in the solar system, based on measurements of heavy radioactive elements, is about 15 billion years, again including some uncertainty. If one accepts a high value of the Hubble constant, and hence a low age for the universe, the simplest big bang model clearly fails, because the universe cannot be younger than the objects it contains. If one chooses a low value for the Hubble constant, it is touch and go.

Rather than consider alternatives to the big bang, cosmologists contort themselves and propose that the rate of expansion is just small enough to accommodate the oldest well-documented stellar ages. Or they vary the big bang model by invoking an arbitrary parameter, called the cosmological constant. In this version of the story, the initial big bang was followed by a waiting period and then a further expansion.

The pervasive cosmic microwave background was predicted by the big bang theory and is still considered to be one of its strongest pieces of supporting evidence. Measurements now, however, show that the background radiation is extremely smoothly distributed. Maps of galaxies, on the other hand, show structure on all scales.

According to the standard version of big bang theory, matter and radiation were strongly coupled together in the early universe, and only later did the two go their separate ways. If this were so, the cosmic microwave background would show some imprint from the lumpy matter distribution that led to the formation of galaxies. In actuality, however, the cosmic microwave background appears smooth to at least one part in 100,000, close to the level at which the big bang must be abandoned or significantly modified.

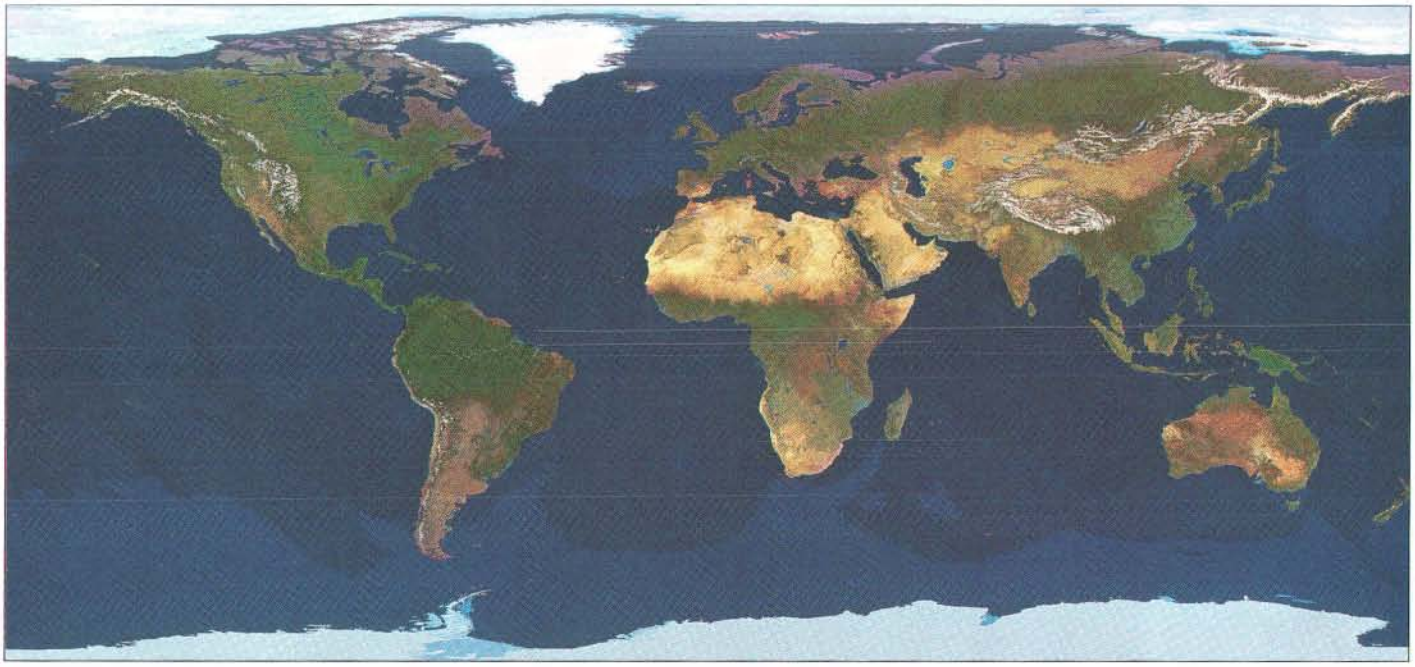
Within the framework of the hot big bang, there is no satisfactory theory of how galaxies and larger structures formed. Galaxies cannot form by gravitational collapse in an expanding universe unless one assumes without explanation that large density fluctuations were present in the early universe. Under the influence of particle physicists, cosmologists are now proposing that these fluctuations occurred at an early stage of the big bang or else were caused by exotic entities such as cosmic strings. None of these ideas can be directly tested.

The inflationary model, a pet idea of the past decade, holds that a period of extremely rapid expansion in the early universe accounts both for the smoothness of the cosmic microwave background and for the amount of matter present in the universe. But again, inflation is an untestable addition to the lore of the big bang.

This form of inflation is arbitrary, and our successors will wonder when it goes out of favor, as the history of science suggests it will, why it was so popular. The inflationary idea occurs quite naturally in the steady state cosmology. I believe there is considerable merit in a variant of this that was recently described by Arp, Fred Hoyle, Jayant V. Narlikar, N. C. Wickramasinghe and me. In it, continuous creation takes place in a series of little big bangs, and in such a model the cosmic microwaves are generated by the galaxies and never coupled to them. This model is at least one viable alternative that can explain all that we can see. There may be others.

Why then has the big bang become so deeply entrenched in modern thought? Everything evolves as a function of time except for the laws of physics. Hence, there are two immutables: the act of creation and the laws of physics, which spring forth fully fashioned from that act. The big bang ultimately reflects some cosmologists' search for creation and for a beginning. That search properly lies in the realm of metaphysics, not science.

GEOFFREY BURBIDGE is professor of physics at the University of California, San Diego, and former director of the Kitt Peak National Observatory.



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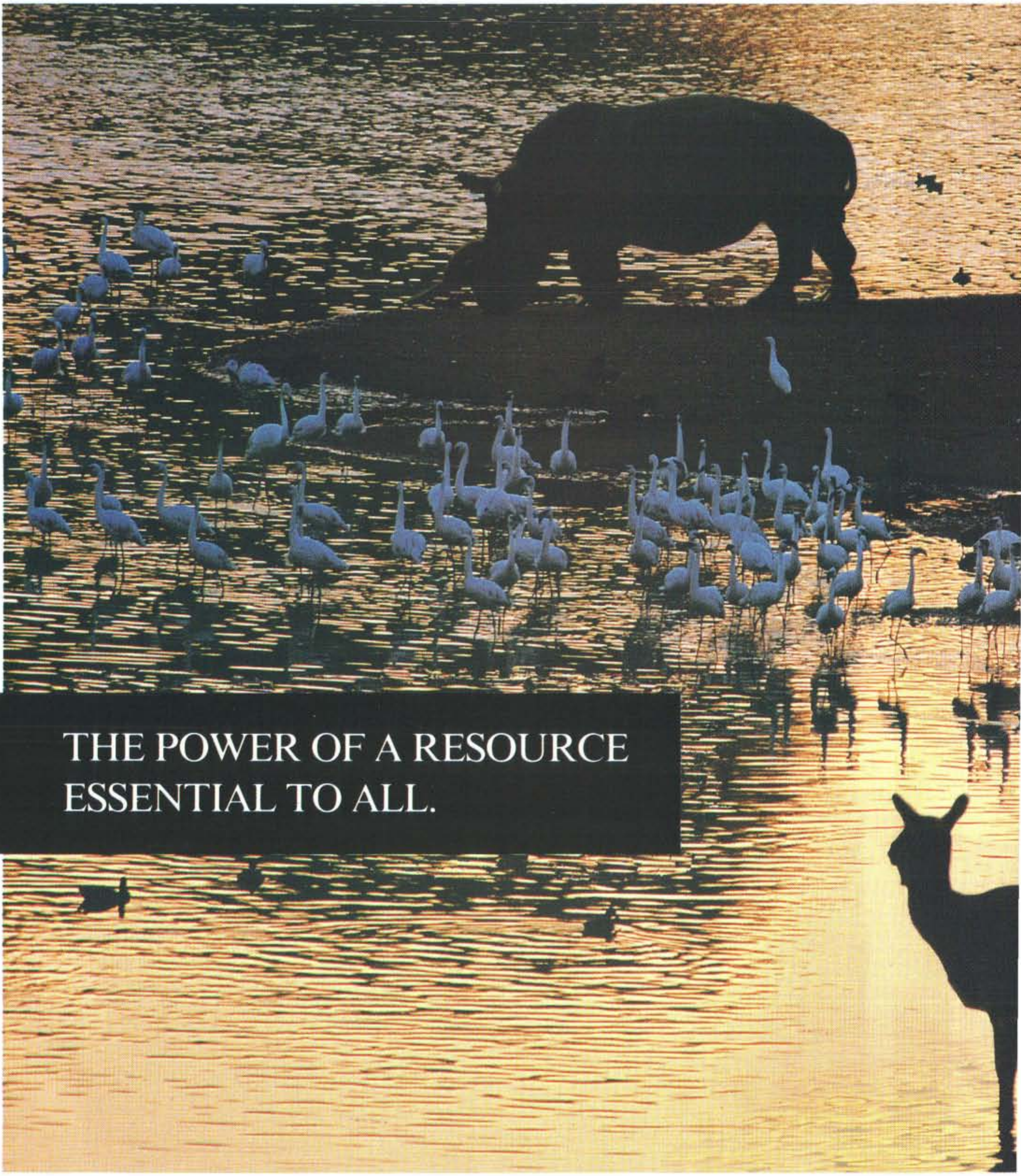

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